Dredged Material Containment

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**US Army Corps
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Report to

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on

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Environmental Baseline Data Collections
and Site Evaluations

Long Island Sound Container Disposal Study

Clinton Harbor, Connecticut

Taxon, Inc.

The Center for the Environment and Man, Inc.

Marine Surveys, Inc.

Environmental Concern, Inc.

March 1982

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS

where

    d = grain meter (in cm)

    ν = kinetic viscosity ($\sim 10^{-2}$ poise)

    S = relative density of the particle (i.e., quartz = 2.65)

    g = acceleration due to gravity (980 cm/s^2)

Knowing the sediment and fluid properties above, one can calculate S_* and from Figure 5, the critical value of dimensionless shear ψ, the Shields parameter, can be estimated. Where:

$$\psi = \frac{\tau_o}{(S-1)\ \rho g d} \tag{2}$$

and

    τ_o = bottom shear stress (in dynes/cm^2)

    S = relative particle density (2.65 for quartz)

    p = density of salt water (~ 1.04), fresh = 1.0 g/cc

    g = 980 cm/s^2

    d = grain diameter (in cm)

Solving for τ_o one can then estimate the minimum bottom shear stress, and the minimum critical shear velocity (u_*) for initiating sediment motion, assuming a fully developed flow over a flat bottom.* J. C. Harms (1969) illustrates (Figure 6) how the values of the Shields parameter ($\theta=\psi$) might vary from the flat plate condition to low and high energy ripple conditions. At our stations where ripples are present (see Figures 7 and 8), a large range of τ_o and u_* is indicated. The combined wave and current problem (Grant and Madsen, 1982) is much too complex for the limited data available. Therefore, we will use the flat plate comparison as a conservative estimate of the mean bottom shear stresses and critical shear velocities present.

To estimate potential depth-averaged velocities $\bar{u}$ in the field environment, a Reynolds number can be estimated for the flow regime. Moreover, assuming that in a tidal current we have fully developed turbulent flow, where $u_* k_s/\nu > \approx 70$ (i.e., boundary effects are transitional), we can estimate $\bar{u}$ in a logarithmic velocity distribution where:

$$\frac{u}{\bar{u}} = (\frac{1}{\kappa}\ \ln\ \frac{y}{k_s} + B_s) \tag{3}$$

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*

    As $u_*^2 = \sqrt{\tau_o/\rho}$

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Background

Clinton Harbor, Connecticut, is one of several locations in the Long Island Sound area being considered for construction of a dredged material semi-containment facility (DMCF). A DMCF is a structure designed to prevent either the dredged material or the leachate within it from being transported away from the disposal site and thereby being made available for reentry into the natural ecosystem. The concern is primarily with highly polluted or toxic substances, but is is desirable to contain relatively clean dredged material as well.

Consideration of DMCFs as a disposal alternative has been motivated by expressed concerns on the (purported) pollution impacts of open-water disposal over the long-term. The New England Division, Corps of Engineers (NED/COE) is conducting the multi-phased **Long Island Sound Dredged Material Containment Study**, authorized by Congress in May 1977, to examine the feasibility of the containment alternative, to screen potential DMCF sites, to perform environmental baseline field surveys and assessments, and to assess economic and social impact analyses. This study is part of the activities directed to environmental baseline field survey and assessment.

The proposed disposal location, as shown in Figure 1-1, is located to the west of the Federal navigation channel and adjacent to existing beach and salt marsh lands near Hammonasset State Park. An opportunity exists to expand the Hammnonasset marsh and create additional salt marsh valuable for wetland habitat. Two sizes of the DMCF are considered to account for possible variations in the amount of dredged material to be disposed. The smaller DMCF has an area of approximately 40 acres and the larger DMCF has an area of approximately 135 acres.

Because the objective of the Clinton Harbor DMCF is expansion and protection of the existing marsh area, only a low dike will be constructed, using dredged material faced with two feet of riprap for erosion protection. In its final form, the containment facility would consist of channels for tidal movement with vegetative areas in between, similar to the neighboring marsh. The Clinton DMCF is expected to be filled during the course of one year, using a hydraulic dredge and floating pipeline transport and disposal. Within two or three years after filling, the dike and dewatered areas within the DMCF would be covered with plantings established during marsh creation.

The following labels appear on the chart:

CLINTON

Large Containment Site

Small Containment Site

CLINTON HARBOR SITE (NOAA CHART 12374)
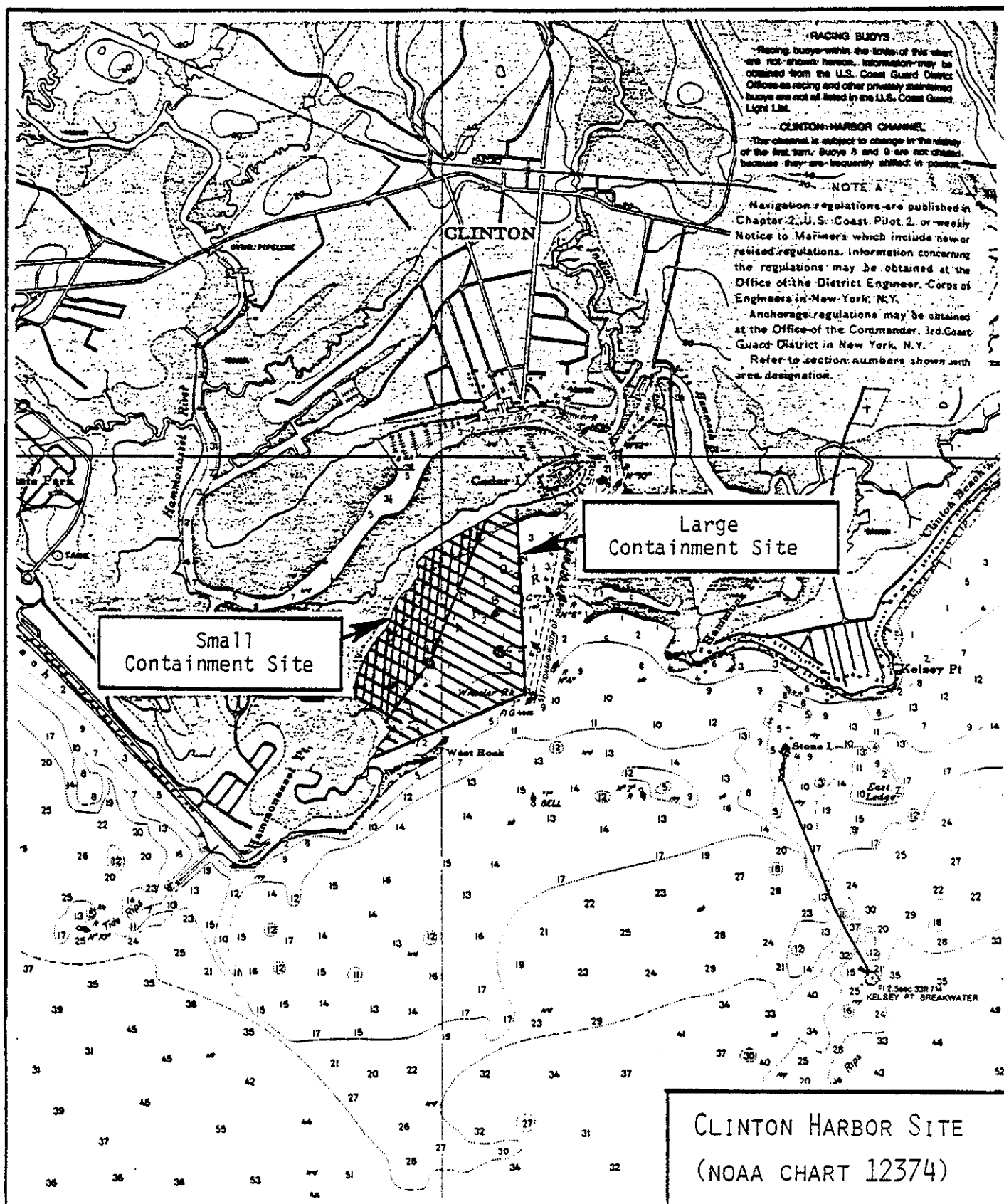
Figure 1-1.   Proposed location of prototype dredged material containment facility.

2.0   STUDY OBJECTIVES AND ORGANIZATION

This document presents the results of a multidisciplinary environmental survey of Clinton Harbor conducted under the terms of Contract No. DACW33-81-C-0116 to Taxon, Inc. The objectives of the survey were to identify and document the physical and ecological conditions of the area, identify and classify habitat types, and determine the habitat value and environmental acceptability of constructing a DMCF.

In order to satisfy the contract objectives, Taxon, Inc., assembled and coordinated a project team comprising the following subcontractors:

o   Ocean Surveys, Inc., Old Saybrook, CT
      Collection of physical oceanographic data.

o   The Center for the Environment and Man, Inc., Hartford, CT
      Tidal hydrodynamic modeling.

o   Marine Surveys, Inc., New Haven, CT
      Sediment-water interface photography and habitat evaluation.

o   Taxon, Inc., Salem, MA
      Survey of benthic macrofauna, finfish, shellfish, algae, and marsh plants.

o   Environmental Concern, Inc., St. Michaels, MD
      Marsh-creation feasibility evaluation.

This report is organized in sections corresponding to the results of the various subcontractors. This section presents some background information on the Clinton area, the proposed maintenance project and the proposed marsh creation. It includes summaries of the results of each of the program component studies, and presents the joint conclusions and recommendations of all participants in the study. Section II presents the results of the tidal hydrodynamic simulation modeling by The Center for the Environment and Man, Inc., based upon data collected and synthesized by Ocean Surveys, Inc. Section III includes the results of the sediment-water interface photography and resultant habitat evaluations and productivity estimates prepared by Marine Surveys, Inc. Section IV reports the results of a biological survey of the harbor conducted by Taxon, Inc., and includes data on benthos, finfish, shellfish, algae and marsh plants in the Harbor. Section V, prepared by Environmental Concern, Inc., is an evaluation of the feasibility of creating marsh habitat on the area occupied by a DMCF.

3.0   RESULTS

3.1   Tidal Hydrodynamic Simulation

Review of results of the prototype data collection activities in the middle portion of Clinton Harbor indicates that circulation characteristics are strongly influenced by wind direction. Winds from the south and west tend to cause dominant current flows toward the eastern portion of the middle harbor and Wheeler Rock. Winds from the north and east tend to cause dominant current flows further to the west over the proposed DMCF site and the West Rock area.

A mathematical model which simulates tidally induced current flows in the harbor was used to assess potential changes in existing circulation characteristics due to alternative DMCF configuration in the middle harbor. The model was calibrated and verified using prototype data obtained by current meter measurements and drogue survey. It was concluded that the model adequately represents existing circulation characteristics based on statistical comparison of simulated versus prototype maximum and mean velocities and graphical display of current velocities and directions.

It is emphasized that the mathematical model does not incorporate representations for wave-induced turbulence and mixing-factors which are believed important in the overall water energy regime in the vicinity of the proposed DMCF site. Conclusions on circulation changes potentially resulting from DMCF placement in the middle harbor should be conditioned by this limitation of the mathematical simulation model, particularly where an energy reduction is projected.

Field data collected for the middle portion of Clinton Harbor, in or near where the proposed DMCF is to be located on the western side, indicate that tidal waters comprising the tidal prism flowing to and from the inner harbor and associated marshlands routinely pass over the DMCF site. That is, tidal flows are not restricted to the Federal navigation channel on the eastern side of the middle harbor.

Simulations of tidal circulation indicate that placement of a DMCF of the sizes considered will tend to restrict flows more toward the eastern portion of the middle harbor and increase peak and maximum velocities in that area. The degree of increase is generally proportional to the size of the DMCF. On the south size of the DMCF site, near West Rock, material placement will reduce tidal circulation which formerly passed over the DMCF site.   There is a potential that wave refraction/diffraction patterns in the middle harbor would be modified by DMCF placement. A postulate--as yet unanalyzed--is that wave energy could be focused more toward the eastern portion of the harbor in a manner similar to the predicted increase in tidal current velocity.

3.2   Sediment Profile Photogrammetry

Much of the outer Clinton Harbor bight in September was dominated by the presence of rippled bottom, indicating general bottom instability. These ripples were predominantly asymmetric, suggesting they were generated by unidirectional tidal flow. However, some ripples were found to have a more complex geometry, presumably related to the interaction of tidal flow with wind-generated waves. The area of unstable bottom increased in October, including areas in the eastern harbor which appeared stable in September.

Modal grain-size was estimated by visual comparison of the sediment-profile images with images of known sediment types. This modal grain-size was then entered into Shields' curve. This allowed the estimation of maximum bottom shear stress for the area of rippled bottom. The depth-averaged velocities were calculated and determined to conservatively range from 36 to 63 cps (1.2 to 2.0 fps).

Based upon the sediment profile photographs, all stations in September with silt or very fine sand substratum appeared to be in Stage I succession. All stations were aerobic and no pockets of methane gas, indicative of biological degradation, were observed. The October faunal and habitat conclusions were comparable to those from September.

The present biological habitat value of the area proposed for the DMCF was judged to be relatively low due to chronic physical disturbance. Most of the resident communities in this area were in low order successional stages; this community type has the potential for high productivity if the frequency of disturbance is not too high. Secondary production estimates, based on standing stocks of dominant infaunal species, were found to be well below those documented in nearby strata with greater stability.

The creation of the proposed marsh area could potentially increase the biological habitat value of the harbor complex through increased habitat diversity and enhanced productivity. In addition to the beneficial effects of the marsh, the proposed stone containment structure would greatly increase the substratum available for hard-bottom communities in a manner analogous to that documented for artificial reefs. The construction of the DMCF as proposed can only enhance the biological value of the area.

3.3 Biotic Survey

The September benthic macrofaunal sampling indicated four basic faunal provinces within the study area. One of these occupied the deeper offshore muds beyond the harbor proper and was occupied by a "typical" Long Island Sound soft-bottom community. A second area, comprising the shallow subtidal zone of the proposed disposal area, was occupied by a community wholly different from that found offshore; species which were common at one location tended to be absent from the other. The majority of the disposal area was occupied by a community which was very closely related to that seen in the shallow subtidal but which also contained species generally not seen further inshore. Finally, the deeper areas of the outer harbor contained a community which comprised components of the other three community types.

Benthic infaunal diversity and density were both greatly increased in October. The pattern of station groups was very similar to that seen in September: an offshore group of stations, a shallow subtidal group occupying the extreme inshore area of the disposal site, and a group of stations occupying the deeper areas of the harbor. Although some individual stations, particularly those at the group boundaries, changed groups between samplings, the general pattern was consistent.

The results of the benthic survey indicate that Clinton Harbor appears to be a relatively unimpacted and well-balanced estuarine ecosystem. No evidence was found to indicate changes in natural communities due to human activity and there was generally little evidence of stress due to natural conditions. The comparatively low richness and density at some outer harbor stations is evidently related to natural conditions such as sediment type or exposure.

In the proposed disposal area at Clinton Harbor, the resident faunal community appears to be normal, well-balanced, and typical of many northeast estuaries with similar sedimentary and hydrographic regimes. Species such as Tellina agilis and Streblospio benedicti, the most characteristic species at Clinton, are reported from many areas and form the basis of what may be considered the normal muddy-sand community.

Benthic invertebrates are a valuable food source for the bottom-feeding fishes, primarily winter flounder, in the study area. Although the removal of this food source due to DMCF construction would seemingly produce a resultant decrease in finfish stocks, there is evidence to suggest that the reverse may be true in this case. Productivity in the area, as evaluated by MSI, was found to be very low, presumably due to chronic physical disturbance. The combination of greater bottom stability

6

within the shallow embayment proposed by Dr. Garbisch's design and the usually highly-productive hard-bottom community which will occupy the stone containment breakwater will probably result in a net gain in available food resources for bottom fish.

No shellfish were found in any of the subtidal shellfish samples. Based upon other evidence and the benthic sampling, it was apparent that hard clams (M. mercenaria) and bay scallops (A. irradians) exist in this area but they are evidently too sparse to be of commercial importance.

A localized population of oysters (C. virginica) was found in the intertidal zone at Hammonasset State Park. Although shellfish densities in this area were moderately high, the limited extent of the population would preclude anything more than a casual recreational fishery. A series of samples from the shoreline failed to indicate the presence of significant populations of softshell clams (M. arenaria).

Fifteen finfish species were collected in the harbor, three of which were classified as dominants: winter flounder, summer flounder, and silversides. For both flounder species, scale samples indicated that the resident population at Clinton comprises primarily younger fish, with older individuals presumably being found further offshore. It is difficult to extrapolate this one-time sampling to produce a more comprehensive seasonal picture of finfish populations in the harbor. Because the age structure of winter flounder indicates that spawning occurs in the Clinton Harbor system, older individuals of this species would be expeced to move into the area in the late winter/early spring for that purpose. Summer flounder do not exhibit the same migratory pattern, and their incidence in the harbor is probably more constant through the year. Similarly, the population of silversides would not be expected to vary seasonally due to migratory behavior.

Gut content analysis indicated that decapod crustaceans, primarily the sand shrimp, Crangon septemspinosa, were the most common food for summer flounder. Winter flounder, however, fed predominantly on infaunal invertebrate species, particularly polychaete worms of the family Spionidae which were commonly a major component of the benthic community throughout the harbor. Winter flounder also fed upon bivalves, with the razor clam, Ensis directus, being encountered frequently. Silversides were determined to be plankton feeders. Without additional data, it is impossible to speculate on potential seasonality in diet for these species, but it is reasonable to assume that it must be at least partially controlled by seasonal variations in the benthos.

7

Most of the intertidal and shallow subtidal bottom in the area of the proposed DMCF at Clinton is unsuitable for algal colonization. Significant algal populations were located in three spatially-restricted areas: the rocks comprising the southwest boundary of the harbor, salt pannes within Hammonasset Marsh, and a small tidal creek draining the marsh in the vicinity of Hammonasset State Park.

The rock substratum community was the most diverse, supporting over 30 species of algae. These were primarily found in the lower intertidal and subtidal zone, and primarily on the outer face of the rock dike at Hammonassett Point. Species found in this area were typical and included Irish moss (Chondrus crispus) and wrack (Ascophyllum nodosum). Although the only examination of this rock substratum community conducted for this report was confined to attached macroalgae, studies by Taxon at Plymouth, Massachusetts, have shown such habitats also support exceedingly dense and diverse faunal communities. The habitat surveyed is similar in many important characteristics to that which will be created by the stone containment breakwater. The diverse algal community found at Hammonasset Point is indicative of the type of community which should be expected to develop on the breakwater.

The salt panne algal community had very low species richness with only eight species being collected. Total algal cover was less than 20 percent of available substratum. Dominant members of this community included Cladophora albida, Enteromorpha intestinalis, and Ulva lactuca.

The bottom of the tidal creek contained cobbles and oysters, and was heavily colonized by macroalgae. The red alga Gracilaria foliifera was the dominant species here, along with the green alga U. lactuca.

The upper areas of Hammonasset Marsh supported a suite of vascular plant species which were typical of New England salt marshes. In the area of Hammonasset State Park, the marsh grass Spartina alterniflora was the dominant species in the intertidal zone, being replaced by S. patens in the vicinity of Cedar Island.

3.4 Marsh Creation Feasibility and Design

The site was determined to have high potential for biological enhancement. Dredged material disposal and landscaping could be designed to offer a diversity of habitat types. Existing intertidal shores could be retained and, under the protected environment, acquire a layer of finer grained sediments that would provide an improved habitat for benthos. New intertidal dredged material exterior areas could be developed to provide expanded areas of mudflat marsh edge. New dredged material interior areas could be developed to provide a combination of low and high elevation

8

salt marsh and high elevation unvegetated areas to promote tern nesting. Existing shallow water areas could be retained as a refuge and feeding area for fish. The new habitat types would have potential educational value to both the local community and to visitors to the Hammonasset State Park.

A sequential development of the site, concurrent with periodic dredged material disposal needs, is suggested. The present design reflects a developed site having the following characteristics:

1. Total capacity of 971,000 cu yd of dredged materials having:
   - 363,000 cu yd of fine grained materials,
   - 608,000 cu yd of sand.

2. Fifty-four acres of Spartina alterniflora salt marsh developed on fine grained materials at elevations between 4.0 ft and 5.0 ft.

3. Thirteen acres of Spartina alterniflora salt marsh developed throughout the sand containment structure at elevations between 2.5 ft and 5.0 ft.

4. Thirteen acres of Spartina patens salt marsh developed throughout the sand containment structure at elevations between 5.0 ft and 6.0 ft.

5. Fifteen acres of unvegetated intertidal sand flat at elevations between 0 ft and 2.5 ft.

6. Thirteen acres of unvegetated to sparsely vegetated sand nesting area at elevations between 6.0 ft and 7.0 ft.

7. Twenty-eight acres of shallow subtidal area at elevations between 1 ft and 0 ft.

The establishment of S. alterniflora between elevations 4.0 ft to 5.0 ft can be accomplished by seeding. The establishment of this species between elevations 2.5 ft and 4.0 ft and of S. patens between elevations 5.0 ft and 6.0 ft must be accomplished by transplanting peat-potted nursery stock. Sandy areas between elevations 6.0 ft and 7.0 ft might be sparsely vegetated by a combination of Panicum virgatum (switchgrass), Ammophila breviligulata (beachgrass), and Myrica pensylvanica (bayberry). Commercial nursery plant materials of these species are recommended. Regional plant materials or ones obtained from areas south to Virginia would be acceptable to use.

4.0 CONCLUSIONS

The purpose of this program was to develop basic ecological information necessary to evaluate the feasibility and desirability of creating a dredged material containment facility in outer Clinton Harbor, Connecticut, and establishing a viable salt marsh ecosystem on the deposited spoils. In order to address these points, investigations were conducted in three areas: (1) a hydrodynamic simulation was used to investigate the effects of the containment structure on water movement in the harbor system; (2) two independent biological surveys were conducted to evaluate the habitat value of the existing communities occupying the proposed disposal area in relation to the remainder of the harbor; and (3) a marsh creation feasibility study was conducted to determine the utility of the site for marsh creation. These studies may be thought of as addressing the following increasingly complex series of questions, respectively: Will the proposed plan result in detrimental alteration of water movement patterns? Is the present ecological value of the area sufficiently high to make any alterations inadvisable? Can a viable marsh ecosystem be established on the deposited spoils and, if so, will the ecological value of the marsh be greater than the value of the existing natural community?

As the hydrodynamic simulation indicated, tidal current patterns and flushing characteristics of the Harbor do not appear to be detrimentally altered by the proposed development. The most significant effect of DMCF construction would be an increase in tidal velocities in the outer harbor. This increase would be on the order of 2x to 3x and would presumably increase sediment transport in this area. Data developed by the biological habitat evaluation study indicate that most sediments in the outer harbor area are particularly unstable under present conditions with sediments to the east of the channel, where tidal velocities would be most increased due to DMCF construction, appearing to be at the point where such changes in tidal velocities could produce significantly increased sediment transport. The exact nature and effects of this increased transport could not be evaluated within the scope of the present study. Also, the model employed for the simulation did not incorporate representations for wave-induced turbulence and mixing, factors which could be of considerable importance and which must be evaluated in order to adequately assess circulation and transport changes.

Within the area of the outer harbor which would be occupied by the proposed facility, sediments were also determined to be unstable and in a state of chronic minor, and periodic major, resuspension. This type of bottom does not allow the

establishment of complex, balanced biological communities and the resident macro-faunal community in this area was generally characterized by species known as Stage I colonizers which are capable of rapid exploitation of a substratum following physical disturbance. These include the polychaete Streblospio benedicti and the bivalve, Tellina agilis, which may be considered the dominant species in the proposed disposal area. In addition, this type of bottom is usually unsuited to the development of commercially valuable populations of edible shellfish, and no significant populations were found during the course of this study with the exception of a small oyster population at Hammonasett State Park.

Although some communities with characteristics similar to those at Clinton can exhibit elevated productivity, this does not appear to be true in this case. Based upon biomass and life-history data, the estimated annual production in the study area was approximately 10.5 g C m^{-2} yr^{-1}, a value which is relatively low in comparison with other Stage I assemblages in Long Island Sound. It appears, then, that the frequency of physical disturbance in this area is sufficient to limit its value as a habitat. Although it was demonstrated that the species within the area are utilized as food by demersal fishes in the harbor, primarily winter flounder, the low secondary production in the benthos indicates that any impacts to finfish via removal of this food resource would be minimal.

The area was determined to have high potential for biological enhancement through the establishment of a marsh on the deposited spoils. This enhancement would occur in several areas, the most notable of which include: (1) the marsh proper, which would incorporate over 60 new acres of Spartina alterniflora (i.e., "low" marsh) habitat, an extremely productive habitat type which is not presently common in the outer harbor area; (2) nearly 30 acres of shallow subtidal inlet-type habitat, providing area for fish spawning and stable bottom for colonization by productive benthic macrofaunal communities; and (3) nearly 5000 linear feet of rock breakwater, one face of which would provide hard bottom suitable for colonization by an extremely rich and diverse macrofaunal community in addition to habitat for various species of potential commercial importance (lobsters, mussels, crabs).

The investigations undertaken to date indicate no serious adverse impacts from the proposed DMCF construction and have identified several projected benefits. We wish to emphasize, however, that additional studies must be conducted to ensure that adverse impacts will not occur from effects which were outside the scope of the present study. Chief among these would be the potential for large-scale sediment

11

alterations due to increase tidal velocities and diversion of wave energy to other areas of the harbor. To that end, we have developed a series of recommendations for future work which will ensure that any such potential impacts will be fully evaluated. In addition, we have recommended studies which will allow better quantification of the projected benefits of the project.

5.0 RECOMMENDATIONS

5.1 All parties involved in the various phases of this environmental assessment agree that the proposed maintenance dredging and DMCF marsh creation have the potential of producing significant improvement in the biological habitat value of the Clinton Harbor estuarine system. We recommend that additional investigations concerning site feasibility be undertaken.

5.2 In order for any subsequent investigations to have maximum applicability, the engineering aspects of the DMCF must be determined in greater detail. This would include the resolution of such questions as containment size and configuration, location and design of provisions for water circulation through or around the breakwater and the nature of the breakwater itself, specifically whether the bottom is capable of supporting the projected stone structure.

5.3 The work done to date does not address the potential effects of DMCF construction on the sediment budget of the area. Since substratum changes due to this factor could prove detrimental to biological communities at some distance from the site, sediment transport studies must be conducted. The southwest corner of the proposed breakwater would experience the same wave regime as Hammonasset Point, and sediment transport studies in the area of the Point could be applied to predictions of the effects of the breakwater.

5.4 The dike breakwater will present a large area of rock substratum suitable for colonization by attached macroalgae and their associated faunal communities. This could prove to be one of the most beneficial aspects of the project as this type of habitat is known to support communities with high diversity and large standing stocks. The natural rock dike at Hammonasset Point provides an opportunity to evaluate the type of community which will become established on the breakwater. The hard bottom community at Hammonasset Point should be surveyed using SCUBA methodology and the information used to develop estimates of standing stocks and productivity on the new breakwater.

5.5 Although some cursory estimates of benthic productivity were developed for the present study, these values are based on incomplete information. More detailed productivity studies could be performed on the present community in the project area and on local communities representative of the low marsh and tidal creek habitats which would be produced by the proposed marsh creation. Such studies would provide quantitative comparisons between the ecological value of the present community and that of the proposed marsh.

5.6 The data developed for tidal current effects and sediment stability indicate the potential for widespread sediment transport in the harbor should the DMCF be constructed. Wave effects were not evaluated and could have important bearing on this question. Following finalization of breakwater configuration, wave effects and current effects must be modelled simultaneously to address this question.

SECTION II

TIDAL HYDRODYNAMIC SIMULATIONS
OF CLINTON HARBOR, CT

The Center for the Environment and Man, Inc.

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Background

Clinton Harbor, Connecticut, is one of several locations in the Long Island Sound area being considered for construction of a dredged material semi-containment facility (DMCF). A DMCF is a structure designed to prevent either the dredged material or the leachate within it from being transported away from the disposal site and thereby being made available for reentry into the natural ecosystem. The concern is primarily with highly polluted or toxic substances, but is is desirable to contain relatively clean dredged material as well.

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The objective of the Clinton Harbor containment facility is to provide capacity for material dredged from Clinton Harbor. Estimates of the volume of dredged material to be contained range from approximately 300,000 cu yd to more than 700,000 cu yd, depending upon the (as yet not finalized) scope of the Clinton Harbor dredging project.

The proposed disposal location, as shown in Figure 1-1, is located to the west of the Federal navigation channel and adjacent to existing beach and salt marsh lands near Hammonasset State Park. An opportunity exists to expand the Hammnonasset marsh and create additional salt marsh valuable for wetland habitat. Two sizes of the DMCF are considered to account for possible variations in the amount of dredged material to be disposed. The smaller DMCF has an area of approximately 40 acres and the larger DMCF has an area of approximately 135 acres.

Because the objective of the Clinton Harbor DMCF is expansion and protection of the existing marsh area, only a low dike will be constructed, using dredged material faced with two feet of riprap for erosion protection. In its final form, the containment facility would consist of channels for tidal movement with vegetative areas in between, similar to the neighboring marsh. The Clinton DMCF is expected to be filled during the course of one year, using a hydraulic dredge and floating pipeline

1

Figure 1-1. Proposed location of prototype dredged material
containment facility.

2

transport and disposal. Within two or three years after filling, the dike and dewatered areas within the DMCF would be covered with plantings established during marsh creation.

1.2 Study Objective and Scope

This report summarizes the conduct of field and analysis activities directed to evaluation of the proposed Clinton Harbor DMCF on tidal circulation and flushing. Placing of a DMCF in a water area could change circulation patterns within the harbor and lead to unanticipated impacts on the harbor's biota, pollution assimilation capacity and navigation. The objective of the study is then to determine probable changes in circulation characteristics within the harbor as a basis for assessment of related environmental impacts.

The study scope addressed for the circulation assessment consisted of the following:

o Collection of prototype data on tidal current velocity magnitude and distribution in sections of Clinton Harbor at and adjacent to the proposed DMCF site. These data were collected by Ocean Surveys, Inc., and their report is included as Appendix A.

o Formulation, calibration and verification of a two-dimensional mathematical hydrodynamic model using the prototype data.

o Application of the calibrated/verified model is made for the following conditions:
   1. Existing tidal circulation and elevation patterns within the Clinton Harbor estuary for mean and spring tides.

   2. Prediction of changes in tidal circulation patterns for the two alternative DMCF configrations.

1.3 Report Outline

The report generally follows the sequence of activities described above for the study scope. Section 2 summarizes selected available data on physical environmental conditions for Clinton Harbor. Section 3 presents information on the two-dimensional hydrodynamic model and its application to Clinton Harbor. Evaluations of the proposed DMCF on circulation are presented in Section 4. Appendix A presents Ocean Surveys', Inc., data report.

3

2.0 PHYSICAL ENVIRONMENT

2.1 Winds

The outer portion of Clinton Harbor is relatively unprotected from southerly winds--a situation which causes considerable wave action in the DMCF vicinity and has led to erosion of the beach and facing marsh. Table 2-1, extracted from a climatic atlas (GRC,1978), presents long-term wind and other climatic data for Bridgeport, CT (located approximately 35 miles west). Mean wind speed is approximately 10 mph during all seasons. The data indicate that during the recreation season (i.e., June, July and August), the wind is primarily from the southwest. The wind rose of Figure 2-1 is representative of overall wind conditions for much of the north shore of Long Island Sound, including Clinton. The overall dominant wind direction is from the southwest wherefrom it attains the highest velocities.

2.2 Tides

The mean tide level (predicted) in the vicinity of Clinton Harbor is 2.3 feet with an associated mean high water level of 4.7 feet--both referenced to a mean low water (MLW) level of 0.0 feet. Extreme low water is -3.5 feet. Spring tidal range exceeds mean tidal range by approximately 15 percent, which makes it 5.4 feet. Actual tide levels may differ from predicted levels depending on wind (onshore/offshore) and barometric conditions and combinations there.

2.3 Currents

Tidal current velocities were monitored continuously (half-hour averages) at a station near Wheeler Rock for the ten-day period November 4 to 13, 1981. Spot measurements of current velocities were obtained at other selected stations during the survey period. All data are tabulated in the data report included as Appendix A of this report, and the reader is directed there for explanation of methods, locations, etc.

Mean tidal current velocity obtained at the Wheeler Rock site during the survey period is computed as 0.35 fps. Maximum measured velocity near Wheeler Rock was 0.86 fps and minimum measured velocity was 0.03 fps. Figure 2-2 summarizes measured current velocities for the survey period. Spot measurements of current velocities at the harbor mouth near Clinton were approximately 1 fps, although velocities in excess of 2 fps were measured in the channel during the ebb phase of spring tidal conditions and strong southwest winds. Figures 2-3 through 2-6 present results of surface current measurements obtained by drogue survey. The drogue survey results are considered quite valuable for evaluating the effects of wind circulation patterns in the outer harbor. As noted on the figures, the November

TABLE 2-1

NORMALS, MEANS AND EXTREMES

(Table Revised 1975. Base Period for Climatological Normals: 1941-1970)

Month	Temp Normal Daily max	Daily min	Monthly	Extreme Record highest	Year	Record lowest	Year	Heating DD	Cooling DD	Precip Normal	Max monthly	Year	Min monthly	Year	Max in 24 hrs	Year	Snow Max monthly	Year	Snow Max 24 hrs	Year	RH 01	RH 07	RH 13	RH 19	Wind Mean speed	Prevailing dir	Fastest Speed	Dir	Year	Pct sun	Mean sky cover	Clear	Partly cloudy	Cloudy	Precip .01+	Snow 1.0+	Thunderstorms	Heavy fog	Max 90+	Max 32-	Min 32-	Min 0-	Pressure mb
(a)	9				9		9			26		26		26		26		26		26	9	9	9	9	18	7	14	14		26	26	26	26	26	26	26	26	26	9	9	9	9	2
J	36.9	23.4	30.2	65	1974	-3	1968	1079	0	2.71	6.41	1958	0.40	1970	2.42	1962	26.2	1965	11.0	1958	68	70	59	63	13.0	NW	67	34	1964		6.2	9	7	15	11	2	*	3	0	10	25	*	1018.8
F	37.9	23.9	30.9	57	1972	-2	1967	955	0	2.71	6.65	1972	1.44	1954	2.31	1969	24.0	1967	16.7	1969	67	70	58	62	13.9	NW	65	34	1969		6.2	8	7	13	10	2	*	3	0	7	25	*	1017.1
M	45.0	30.8	37.9	67	1974	4	1967	840	0	3.49	9.40	1953	1.16	1965	2.74	1953	21.8	1967	11.1	1967	69	70	58	61	13.7	NW	51	26	1968		6.4	8	9	14	11	1	1	3	0	1	18	0	1016.0
A	56.5	40.3	48.4	85	1974	21	1970	498	0	3.39	8.14	1973	0.84	1963	2.54	1970	3.7	1950	3.7	1950	71	69	54	61	13.0	N	55	32	1962		6.4	7	9	14	11	*	2	3	*	0	4	0	1013.7
M	66.7	49.9	58.3	92	1969	31	1966	225	17	3.57	7.38	1972	0.78	1955	3.23	1968	T	1961	T	1961	79	75	60	67	11.7	E	50	34	1974		6.4	7	10	14	11	0	3	4	*	0	*	0	1013.4
J	76.0	59.8	67.9	96	1974	41	1967	24	111	2.56	17.70	1972	0.07	1949	6.89	1972	0.0		0.0		83	78	62	71	10.5	SW	38	25	1962		6.0	8	10	12	9	0	4	4	1	0	0	0	1015.3
J	81.5	66.1	73.8	100	1966	55	1972	0	273	3.44	12.84	1971	0.82	1954	5.95	1971	0.0		0.0		80	76	59	68	9.9	SW	40	29	1973		6.0	7	13	11	8	0	5	2	4	0	0	0	1014.9
A	80.4	64.9	72.7	93	1969	48	1969	0	241	3.80	13.29	1952	0.77	1972	3.97	1955	0.0		0.0		82	78	60	69	10.0	SW	55	12	1971		5.5	9	11	11	9	0	4	1	4	0	0	0	1017.5
S	74.5	58.4	66.5	93	1966	39	1974	42	87	2.88	7.42	1960	0.43	1959	4.67	1960	0.0		0.0		82	80	61	71	11.1	NE	47	02	1961		5.6	10	9	11	9	0	2	1	1	0	0	0	1017.6
O	65.1	48.5	56.8	86	1967	26	1972	261	6	2.79	10.72	1955	0.33	1963	4.24	1972	T	1972	T	1972	78	77	58	66	11.8	NE	31	24	1967		5.2	11	9	11	6	0	1	2	*	0	1	0	1020.0
N	53.3	38.7	46.0	76	1968	16	1972	570	0	3.83	10.22	1972	1.26	1974	4.07	1954	3.4	1953	5.4	1953	75	77	62	69	12.8	NW	58	14	1964		6.3	8	8	14	10	*	*	1	0	*	8	0	1015.8
D	40.5	27.1	33.8	65	1971	6	1968	967	0	3.44	7.87	1972	0.33	1955	3.69	1968	16.2	1963	7.8	1966	74	75	64	69	12.9	NW	53	25	1962		6.2	9	7	15	11	2	*	2	0	*	21	0	1017.0
YR	59.5	44.3	51.9	100 JUL 1966		-3 JAN 1968		5461	735	38.01	17.70	1972	0.07	1949	6.89	1972	26.2	1965	16.7	1969	75	75	60	67	12.0	SW	67	34	1964		6.0	101	109	155	117	7	22	29	7	22	104	*	1016.4

Elev 17 feet m s l

Ø For period August 1965 through current year.
Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows:
Highest temperature 103 in July 1957; lowest temperature -20 in February 1934; maximum monthly precipitation 18.77 in July 1897; maximum monthly snowfall 47.0 in February 1934.

(a) Length of record, years, through the current year unless otherwise noted, based on January data.
(b) 70° and above at Alaskan stations.
* Less than one half.
T Trace.

NORMALS - Based on record for the 1941-1970 period.
DATE OF AN EXTREME - The most recent in cases of multiple occurrence.
PREVAILING WIND DIRECTION - Record through 1963.
WIND DIRECTION - Numerals indicate tens of degrees clockwise from true north. 00 indicates calm.
FASTEST MILE WIND - Speed is fastest observed 1-minute value when the direction is in tens of degrees.

Figure 2-1.   Annual Long Island Sound Wind Rose, 1965 - 1972.
(source: U.S.A.E.C., 1973)

Figure 2-2. Clinton Harbor, CT. Measured current velocities
summary, Station CM (near Wheeler Rock).

7

Figure 2-3. Drogue survey deployment no. 1, flood current, s.w. wind.

CLINTON HARBOR

Finish

Start

NOTES

1. COORDINATES ARE IN FEET AND IN THE CONNECTICUT STATE COORDINATE SYSTEM

2. SHORELINES ARE APPROXIMATE AND ARE PLOTTED FROM NOAA CHART NO. 12372.

3. COORDINATES FOR CONTROL POINT "HAMM 30" WERE PROVIDED BY THE U.S. ARMY CORPS OF ENGINEERS, NEW ENGLAND DIVISION, AND ARE CONSIDERED UNOFFICIAL. POSITION OF "WEST" IS LOCATED TO ACCURACY OF NOAA CHART NO. 12372.

4. THIS CHART WAS PREPARED BY OCEAN SURVEYS, INC. THE INFORMATION DEPICTED REPRESENTS THE RESULTS OF A SURVEY PERFORMED BY OSI ON 11-12 NOVEMBER 1981, AND CAN ONLY BE CONSIDERED AS INDICATING THE CONDITIONS EXISTING AT THE TIME OF DATA ACQUISITION.

LEGEND

△ CONTROL POINTS
○ VERTICAL PROFILE STATIONS
ↆ ↋ CHANNEL MARKERS

0   800

SCALE IN FEET
CHECK GRAPHIC SCALE BEFORE USING

DEPLOYMENT NUMBER 1									
FLOOD CURRENT S.W. WIND						11 NOVEMBER 1981			
DROGUE SYMBOL	DEPLOYMENT PERIOD	AVERAGE SPEED (FPS) BETWEEN POSITION FIXES							
		1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9
○	0842-0940	1.22	0.97	2.17	0.65	1.03			
▢	0843-0950	0.90	0.77	0.62	1.08	0.49			
◇	0843-0951	0.53	0.84	1.09	0.80	0.50			
▽	0844-0949	0.93	0.72	1.50	0.72	1.12			
★	0845-0947	0.96	0.88	0.69	1.13	0.90			
●	0845-0948	0.91	1.09	1.09	0.90	0.50			

OCEAN SURVEYS, INC.
OSI
OLD SAYBROOK, CONNECTICUT

TAXON, INC

DROGUE TRACKS
FLOOD CURRENT - SOUTHWEST WIND
CURRENT AND CIRCULATION SURVEY
CLINTON HARBOR, CONNECTICUT

| SCALE 1"=200' | CONTOUR INTERVAL N.A. | SURVEY DATE 11-12 NOV 1981 |
| DRAFTED BY V. KASK | DATE 25 NOV 1981 | DWG. NO 72163-A |

Start

CLINTON HARBOR

Finish

LOCATION MAP

LONG ISLAND SOUND

NOTES

1. COORDINATES ARE IN FEET AND IN THE CONNECTICUT STATE COORDINATE SYSTEM.

2. SHORELINES ARE APPROXIMATE AND ARE PLOTTED FROM NOAA CHART NO. 12373.

3. COORDINATES FOR CONTROL POINT "MARK 88" WERE PROVIDED BY THE U.S. ARMY CORPS OF ENGINEERS, NEW ENGLAND DIVISION, AND ARE CONSIDERED UNOFFICIAL. POSITION OF "WEST" IS LOCATED TO ACCURACY OF NOAA CHART NO. 12373.

4. THIS CHART WAS PREPARED BY OCEAN SURVEYS, INC. THE INFORMATION DEPICTED REPRESENTS THE RESULTS OF A SURVEY PERFORMED BY OSI ON 11-12 NOVEMBER 1981, AND CAN ONLY BE CONSIDERED AS INDICATING THE CONDITIONS EXISTING AT THE TIME OF DATA ACQUISITION.

LEGEND

△ CONTROL POINTS

○ VERTICAL PROFILE STATIONS

CHANNEL MARKERS

0   800

SCALE IN FEET
CHECK GRAPHIC SCALE BEFORE USING

		DEPLOYMENT NUMBER 2							
EBB CURRENT						11 NOVEMBER 1981			
S.W. WIND									
DROGUE SYMBOL	DEPLOYMENT PERIOD	AVERAGE SPEED (FPS) BETWEEN POSITION FIXES							
		1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9
⊙	1135-1245	0.96	0.75	0.49	0.55				
⊡	1137-1227	0.68	0.91	0.95	0.63				
◈	1139-1247	0.32	0.48	0.75	0.71	0.64			
▽	1140-1348	0.13	0.34	0.45	0.60	0.64	0.53	0.39	0.52
✦	1141-1348	0.13	0.12	0.37	0.66	0.51	0.61	0.55	0.46
●	1142-1355	0.88	0.13	0.14	0.81	0.21	0.25	0.34	0.35
●	1210-1350	0.10	0.41	0.61	0.46				
●	1222-1321	0.69	0.55	0.45	0.41				
●	1250-1350	0.51							

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OLD SAYBROOK, CONNECTICUT

TAXON, INC

DROGUE TRACKS
EBB CURRENT – SOUTHWEST WIND
CURRENT AND CIRCULATION SURVEY
CLINTON HARBOR, CONNECTICUT

SCALE	CONTOUR INTERVAL	SURVEY DATE
1"=200'	N A	11-12 NOV. 1981
DRAFTED BY	DATE	DWG. NO.
V KASH	23 NOV 1981	72143-9

Figure 2-4.   Drogue survey deployment no. 2, ebb current, s.w. wind.

LOCATION MAP

WESTBROOK

CLINTON

SURVEY AREA

LONG ISLAND SOUND

SCALE 1:80000

CLINTON HARBOR

NOTES

1. COORDINATES ARE IN FEET AND IN THE CONNECTICUT STATE COORDINATE SYSTEM.

2. SHORELINES ARE APPROXIMATE AND ARE PLOTTED FROM NOAA CHART NO. 12372.

3. COORDINATES FOR CONTROL POINT "MAMA 80" WERE PROVIDED BY THE U.S. ARMY CORPS OF ENGINEERS, NEW ENGLAND DIVISION, AND ARE CONSIDERED UNOFFICIAL. POSITION OF "WEST" IS LOCATED TO ACCURACY OF NOAA CHART NO. 12372.

4. THIS CHART WAS PREPARED BY OCEAN SURVEYS, INC. THE INFORMATION DEPICTED REPRESENTS THE RESULTS OF A SURVEY PERFORMED BY OSI ON 11-12 NOVEMBER 1981, AND CAN ONLY BE CONSIDERED AS INDICATING THE CONDITIONS EXISTING AT THE TIME OF DATA ACQUISITION.

DEPLOYMENT NUMBER 3

FLOOD CURRENT   12 NOVEMBER 1981
N.E. WIND

DROGUE SYMBOL	DEPLOYMENT PERIOD	AVERAGE SPEED (FPS) BETWEEN POSITION FIXES							
		1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9
○	0749-0811	0.09	0.04	0.10	0.14	0.23			
◻	0750-1013	0.24	0.13	0.21	0.36	0.45	0.43	0.68	
◇	0751-1012	0.31	0.28	0.29	0.31	0.45	0.44	0.68	
▽	0752-1019	0.26	0.26	0.28	0.36	0.45	0.48	0.63	1.05
★	0753-1024	0.27	0.22	0.33	0.34	0.45	0.45	0.51	
●	0754-1023	0.13	0.22	0.35	0.35	0.43	0.50	0.57	
●	0852-0907	0.86	0.78						
●	0829-0849	0.56							
●	0832-0848	0.82							

LEGEND

△ CONTROL POINTS
○ VERTICAL PROFILE STATIONS
CHANNEL MARKERS

N 154,000

0   800

SCALE IN FEET
CHECK GRAPHIC SCALE BEFORE USING

OCEAN SURVEYS, INC.
OSI
OLD SAYBROOK, CONNECTICUT

TAXON, INC

DROGUE TRACKS
FLOOD CURRENT - NORTHEAST WIND
CURRENT AND CIRCULATION SURVEY
CLINTON HARBOR, CONNECTICUT

SCALE 1"=200	CONTOUR INTERVAL N.A.	SURVEY DATE 11-12 NOV. 1981
DRAFTED BY V. KASA	DATE 25 NOV. 198	DWG. NO. T2163-C

Start

Finish

Figure 2-5. Drogue survey deployment no. 3, flood current, n.e. wind.

LOCATION MAP

WESTBROOK

CLINTON

SURVEY AREA

LONG ISLAND SOUND

•Start

NOTES

1. COORDINATES ARE IN FEET AND IN THE CONNECTICUT STATE COORDINATE SYSTEM.

2. SHORELINES ARE APPROXIMATE AND ARE PLOTTED FROM NOAA CHART NO. 12373.

3. COORDINATES FOR CONTROL POINT "HAMM 80" WERE PROVIDED BY THE U.S. ARMY CORPS OF ENGINEERS, NEW ENGLAND DIVISION, AND ARE CONSIDERED UNOFFICIAL. POSITION OF "WEST" IS LOCATED TO ACCURACY OF NOAA CHART NO. 12373.

4. THIS CHART WAS PREPARED BY OCEAN SURVEYS, INC. THE INFORMATION DEPICTED REPRESENTS THE RESULTS OF A SURVEY PERFORMED BY OSI ON 11-12 NOVEMBER 1981, AND CAN ONLY BE CONSIDERED AS INDICATING THE CONDITIONS EXISTING AT THE TIME OF DATA ACQUISITION.

CLINTON HARBOR

LEGEND

△ CONTROL POINTS

○ VERTICAL PROFILE STATIONS

CHANNEL MARKERS

| 0 | 800 |

SCALE IN FEET
CHECK GRAPHIC SCALE BEFORE USING

Finish

DEPLOYMENT NUMBER 4

EBB CURRENT
N.E. WIND

12 NOVEMBER 1981

DROGUE SYMBOL	DEPLOYMENT PERIOD	AVERAGE SPEED (FPS) BETWEEN POSITION FIXES							
		1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9
○	1056-1250	0.16	0.40	0.66	0.73	0.72	0.94		
◻	1057-1243	0.33	0.57	0.73	0.76	0.85			
◊	1058-1238	0.41	0.61	0.73	0.77	0.83			
▽	1059-1227	0.37	0.52	0.69	0.80				
★	1101-1213	0.43	0.66	0.80	0.59				
●	1103-1155	0.52	0.69	0.79					
●	1105-1215	0.46	0.59	0.67	0.83				
●	1117-1230	0.45	0.66	0.78	0.94	1.03			

OCEAN SURVEYS, INC.

OLD SAYBROOK, CONNECTICUT

TAXON, INC

DROGUE TRACKS
EBB CURRENT-NORTHEAST WIND
CURRENT AND CIRCULATION SURVEY
CLINTON HARBOR, CONNECTICUT

SCALE	CONTOUR INTERVAL	SURVEY DATE
1"=200'	N.A.	11-12 NOV 1981
PLOTTED BY	DATE	DWG NO
V MASK	23 NOV 1981	72163-D

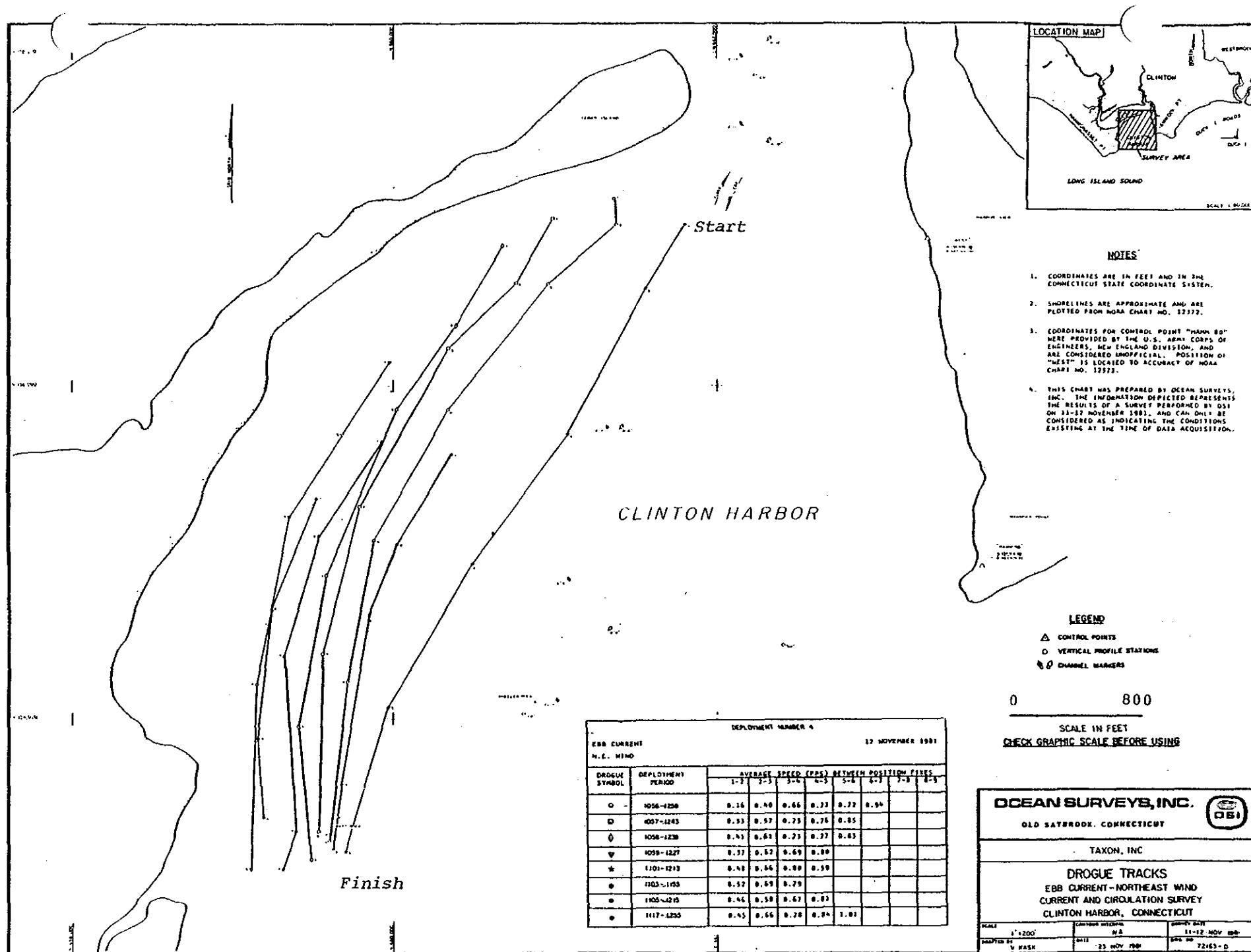Figure 2-6. Drogue survey deployment no. 4, ebb current, n.e. wind.

11, 1981, drogue survey (Figure 2-3, flood, and Figure 2-4, ebb) was conducted during a period of persistent wind (6 to 10 mph) from the southwest. Winds on the second day of the drogue survey on November 12, 1981 (Figure 2-5, flood, and Figure 2-6, ebb) were from the northeast at 3 to 8 mph.

3.0 ESTUARY HYDRODYNAMIC SIMULATION MODEL (EHYDSIM)

3.1 Overview

EHYDSIM is a general purpose mathematical simulation model developed to simulate tidal hydrodynamics in shallow, irregular and non-stratified bays and estuaries. The model was originally developed for the Texas Water Development Board and applied to several Gulf of Mexico coastal embayments and estuaries (Masch, 1971a and b). The EHYDSIM model and accompanying documentations were obtained from the Texas Water Development Board for use on this and other applications.

3.2 Model Description

Basically, EHYDSIM is a computational algorithm using an explicit numerical solution of the basic equations of motion for long-period tidal waves and the continuity equation for unsteady flow. Operation of the model provides for a time history and spatial distribution of tidal amplitude, tidal flow, consecutive net velocities, net flows, tidal prisms and dispersion coefficients in each of the two coordinate directions. The model does not represent variations in the vertical direction. The fundamental theory and development of the basic formualtions for tidal hydrodynamics are described in detail in the literature (Dronkers, 1964; Masch, 1969 and 1971a) and therefore will not be addressed in detail here. The basic tidal hydrodynamic equations are partial differential equations of the forms:

- ### Equation of motion, x-direction

$$\frac{\partial q_x}{\partial t} - \Omega q_y = -gd\frac{\partial h}{\partial x} - gdS_{e_x} + X_w \qquad (3\text{-}1)$$

- ### Equation of motion, y-direction

$$\frac{\partial q_y}{\partial t} - \Omega q_x = -gd\frac{\partial h}{\partial y} - gdS_{e_y} + Y_w \qquad (3\text{-}2)$$

- ### Equation of continuity

$$\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + \frac{\partial h}{\partial t} = r - e \qquad (3\text{-}3)$$

In these equations, the basic unknown quantities are q_x and q_y, the flows per foot of width in the x and y coordinate directions, respectively; and h, the tidal amplitude. Other quantities are defined as follows: t is time; d is water depth equal to (h-z); z is the bottom elevation with respect to msl; q is the acceleration of gravity; Ω is the Coriolis parameter; S_{e_x} and S_{e_y} are the energy slopes in the x and y directions, respectively; X_w and Y_w are the wind stresses per unit density of the water; r is rainfall intensity; and e is the evaporation rate.

Even for the most ideal situations, analytical solutions of these equations are difficult to obtain. Further, complex geometry, interior features and variable boundary conditions make purely analytical approaches unsuitable. For these reasons, numerical methods are utilized to obtain solutions to Equations (3-1), (3-2) and (3-3).

In the numerical approach, the prototype estuary is discretized into computational elements or cells as shown in Figure 3-1. The cells are arranged in space and time so that the output from one element becomes input to the next, and so on. Each input is operated on by the transfer function for the cell, and through an advancing series of spatial and time steps, the functional behavior of the entire system is determined.

Selection of the spatial and time steps is controlled by mathematical and practical considerations involving stability, convergence, compatibility and representativeness. Spatial resolution and detail are determined by the model so that accurate representation of the physical features of the estuary is obtained. There is a tradeoff between model resolution and subsequent computational times (and costs). The following criterion must be maintained for a stable solution:

$$\Delta t \leq \frac{\Delta s}{\sqrt{2gd_{max}}} \qquad (3-4)$$

where Δt is the time step; Δs is the cell size; and d_{max} is the maximum water depth in the estuary sytem.

The model is considered a valid tool to evaluate tidal hydrodynamics in an estuary if the following conditions hold:

o The estuary is vertically well-mixed.

o The long period tidal equations represent the tidal flow behavior in the estuary.

o Wind stress coefficient and Coriolis parameter can be considered constant over the bay.

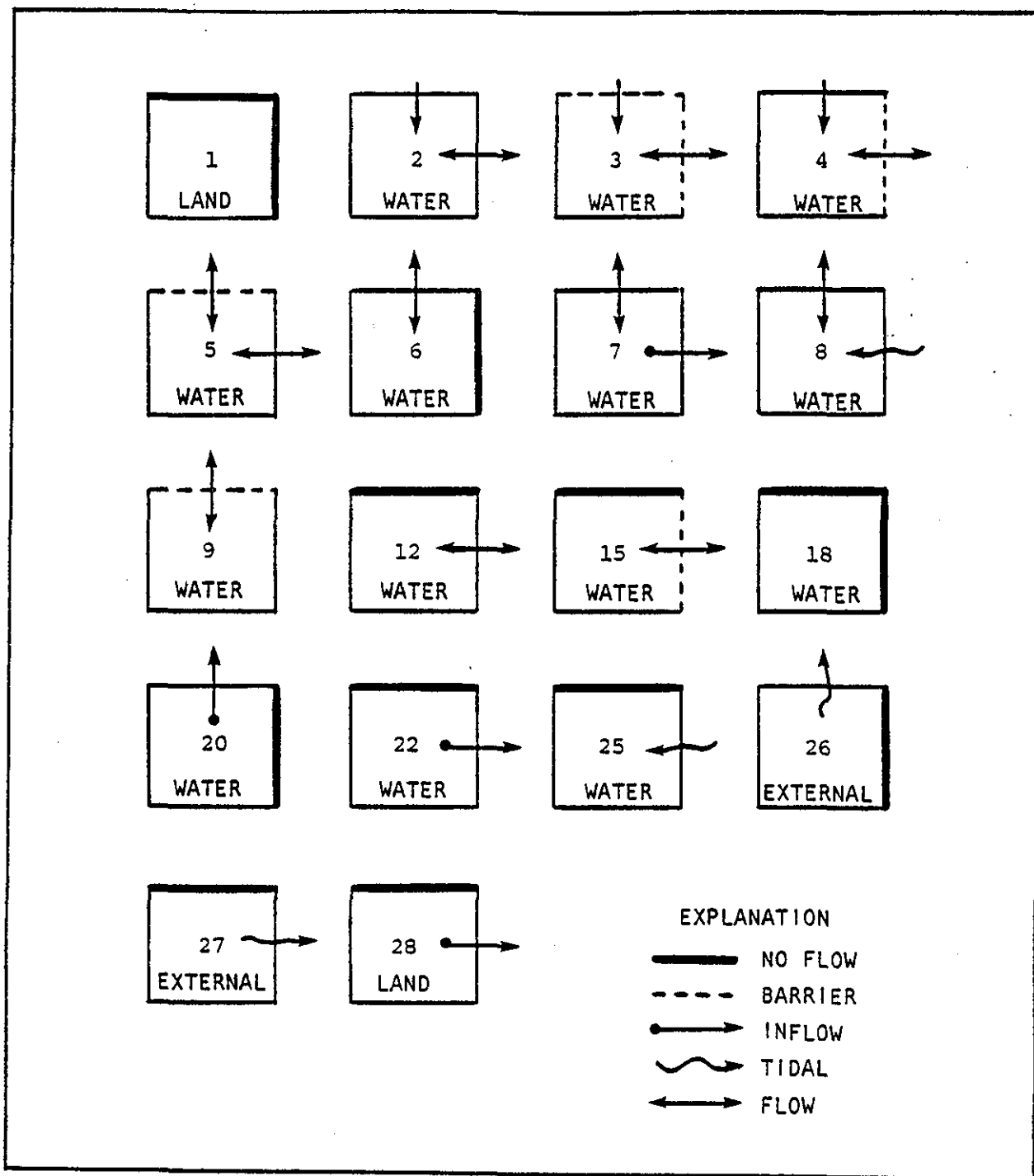Each of these conditions is met for the Clinton Harbor application.

Figure 3-1. Hydrodynamic computational grid cell flag identifications.

3.3 Model Formulation

The EHYDSIM hydrodynamic model is formulated and implemented through the following step-by-step procedure.

(1) Define desired model resolution (i.e., grid cell size).

(2) Establish physical boundaries of estuary system by superimposing a scaled grid mesh of cells over a corresponding map or hydrographic chart.

(3) Establish average mean sea level depths for all computational grid cells.

(4) Assign computational identification numbers or flags for each cell (Figure 3-1). Consider only the top and right boundaries of individual cells when establishing flags.

(5) Assign discharge coefficients and crest evaluations for all submerged barriers.

(6) Establish values of bottom friction in terms of Mannings' "n" coefficient of each cell.

(7) Obtain prototype tidal, hydrologic and meteorologic data appropriate for model calibration and verification.

(8) Assemble data packages and operate model until stable conditions repetitive from one tidal cycle to the next are achieved.

(9) Refine and tune the model by checking prototype tidal calibration plots and flow comparisons until desired accuracy is achieved.

Applications of EHYDSIM to Clinton Harbor proceeded in accord with the step-by-step procedures outlined above. Model resolution or grid cell size was set to 500 feet, which was a compromise between adequate resolution and computer computation times. The implications of such a small cell size are several, including a requirement for a very small time step. Use of Equation 3-4 indicates a time-step requirement of approximately ten seconds. However, trial simulations resulted in selection of a time step of three seconds to achieve numerical stability. Such a small time step results in a computation time of about one hour for simulation of a 25-hour tidal period.

Boundaries of the Clinton Harbor estuary system were established by overlaying a scaled grid mesh of cells over the NOAA hydrographic chart (Figure 1-1). Computational cell flag identifiers were assigned in accord with options summarized in Figure 3-1. Figure 3-2(a) presents MSL depths for the computation grid cells. Average mean sea level depths are assigned based on bathymetry detailed on NOAA Chart 12369. Figure 3-2(b) illustrates the computational cell identifications. Assigned bottom roughness coefficients (i.e., Mannings' "n") are shown in Figure 3-2(c).

(a) Mean Sea Level Water Depths Throughout Bay

I/J	1	2	3	4	5	6	7	8	9	10	11	12
1	0	30	15	0	0	0	9	9	9	9	9	9
2	30	30	15	0	9	9	9	9	9	9	9	9
3	30	25	15	0	9	0	9	9	9	9	9	9
4	30	20	15	0	9	1	1	9	9	9	9	9
5	30	20	10	2	3	3	3	2	0	9	9	0
6	30	20	10	3	4	3	3	3	9	9	9	0
7	30	20	10	10	6	3	3	3	3	9	9	0
8	30	25	15	12	6	5	3	3	3	3	6	0
9	30	25	20	12	9	5	1	1	1	1	0	0
10	35	30	20	12	6	6	0	0	0	0	0	0
11	40	30	15	10	8	3	0	0	0	0	0	0
12	40	30	0	0	0	3	0	0	0	0	0	0

(b) Computational Cell Identifications

I/J	1	2	3	4	5	6	7	8	9	10	11	12
1	1	27	27	1	1	6	6	6	2	2	6	12
2	26	2	12	1	12	6	13	1	2	12	1	12
3	26	2	12	1	12	1	1	1	2	2	12	12
4	26	2	12	1	2	2	12	1	6	2	12	13
5	26	2	2	2	2	2	2	12	1	6	12	1
6	26	2	2	2	2	2	2	12	1	12	1	
7	26	2	2	2	2	2	2	12	1	12	1	
8	26	2	2	2	2	2	2	2	12	1		
9	25	2	2	2	2	2	6	6	6	12	1	
10	26	2	2	2	2	12	1	1	1	1	12	1
11	26	2	6	6	6	12	1	1	6	6	13	1
12	26	25	1	1	1	25	1	1	1	1	1	1

(c) Mannings "N" Bottom Friction Coefficients

1	.000	.050	.010	.000	.000	.010	.010	.010	.010	.010	.010	.010
2	.010	.050	.010	.000	.010	.010	.010	.000	.010	.010	.000	.010
3	.010	.010	.010	.000	.010	.000	.000	.000	.010	.010	.010	.010
4	.010	.010	.010	.000	.010	.010	.010	.000	.010	.010	.010	.010
5	.010	.010	.010	.050	.010	.005	.010	.010	.000	.010	.010	.000
6	.010	.010	.010	.010	.010	.005	.010	.010	.010	.000	.010	.000
7	.010	.010	.010	.010	.005	.005	.005	.005	.010	.000	.010	.000
8	.010	.010	.010	.010	.005	.010	.010	.010	.010	.010	.010	.000
9	.010	.010	.010	.010	.005	.040	.040	.040	.040	.040	.010	.000
10	.010	.010	.010	.010	.005	.005	.000	.000	.000	.000	.010	.000
11	.010	.010	.010	.010	.010	.005	.000	.000	.010	.010	.010	.000
12	.010	.010	.000	.000	.000	.005	.000	.000	.000	.000	.000	.000

Figure 3-2. Model setup for existing conditions - Clinton Harbor.

3.4 Model Calibration and Verification

Model calibration and verification are viewed as two distinct activities relating to establishing the validity of the simulation model vis-a-vis conditions actually existing in Clinton Harbor. Calibration refers to the iterative process of model formulation, simulation and adjustment of parameters until acceptable accuracy relative to prototype data is obtained. Verification involves running the model established by calibration using an independent data set to confirm its validity.

Two subperiods of the total measured velocity data set were selected and used to accomplish model calibration/verification. These are:

Calibration data set:

- 25 hours generally coincident with November 11, 1981.

- Winds 4 to 10 mph from the south and southwest.

- Spring tide conditions.

Verification data set:

- 25 hours generally coincident with November 12, 1981.

- Winds 3 to 8 mph from the north.

- Spring tide conditions.

These two 25-hour subperiods were selected because computation times (and costs) were tractable and encompassed the drogue survey and wind data collection periods.

Calibration of the model is guided by use of evaluation statistics so that subsequent runs can be compared to determine if simulated data more closely match prototype data. In addition to mean and maximum velocities, another evaluation statistic used is the root-mean-square (RMS) error computed as:

$$RMS = \sqrt{\frac{\sum_{n=1}^{N} (d_i)^2}{N}}$$

where: d_i = difference between simulated and measured value.

N = total number of values.

The RMS error statistic is also used to assess the adequacy of the verification period simulation.

Calibration and verification are also aided by graphical plots of simulated velocity vectors which can then be compared to the drogue survey results of Figures 2-3 to 2-6.

Table 3-1 presents results of evaluation statistics developed for the calibration and verification runs.

TABLE 3-1

MODEL EVALUATION STATISTICS

	Mean Velocity		Max. Velocity		RMS
	Meas.	Sim.	Meas.	Sim.	
Calibration Period (11-11-81)	0.42	0.38	0.66	0.68	0.17
Verification Period (11-12-81)	0.40	0.37	0.86	0.59	0.19
Total Period (11-5-81 to 11-13-81)	0.35	0.37	0.86	0.68	0.14

Figures 3-3 (a&b) and 3-4 (a&b) present graphical plots of simulated velocity vectors for flood and ebb tide tidal flow phases for the calibration and verification subperiods, respectively. These figures can be compared with the drogue survey results shown on Figures 2-3 to 2-6 and indicate that, in general, the model adequately reflects the influence of wind direction on circulation patterns in Clinton Harbor.

(a) Flood tide
    (compare with
    drogue survey
    data shown on
    Figure 2-3).

(b) Ebb tide
    (compare with
    drogue survey
    data shown on
    Figure 2-4).

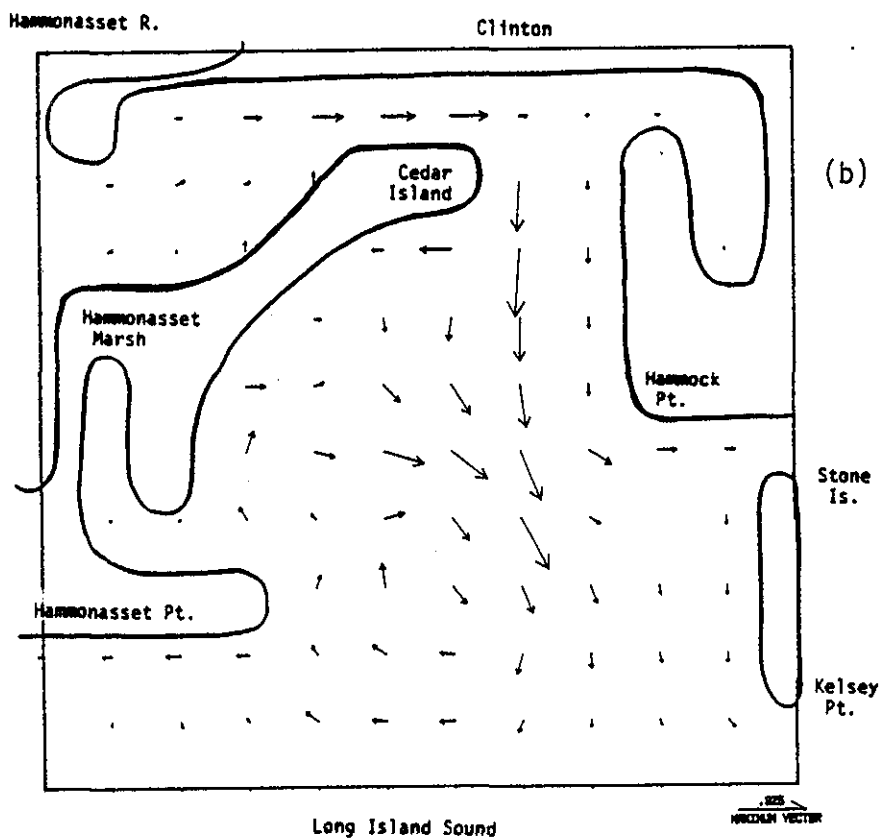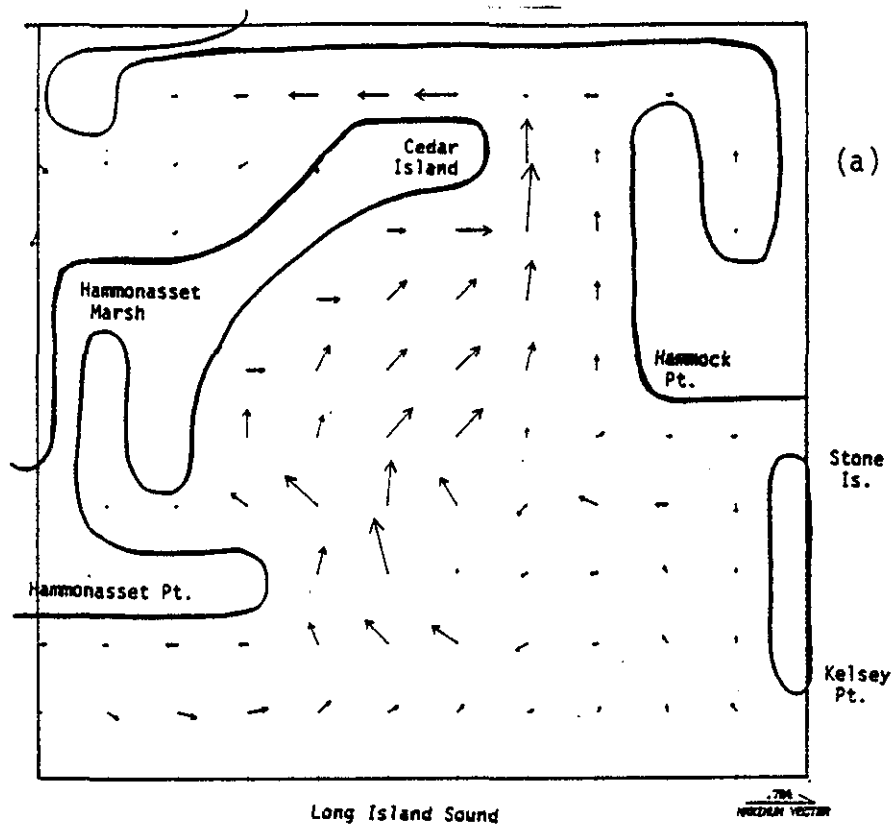Figure 3-3. Simulated velocity vectors for Clinton Harbor -
             calibration period, SSW wind at 10 mph.

20

(a) Flood tide
(compare with
drogue survey
data shown on
Figure 2-5).

Long Island Sound

(b) Ebb tide
(compare with
drogue survey
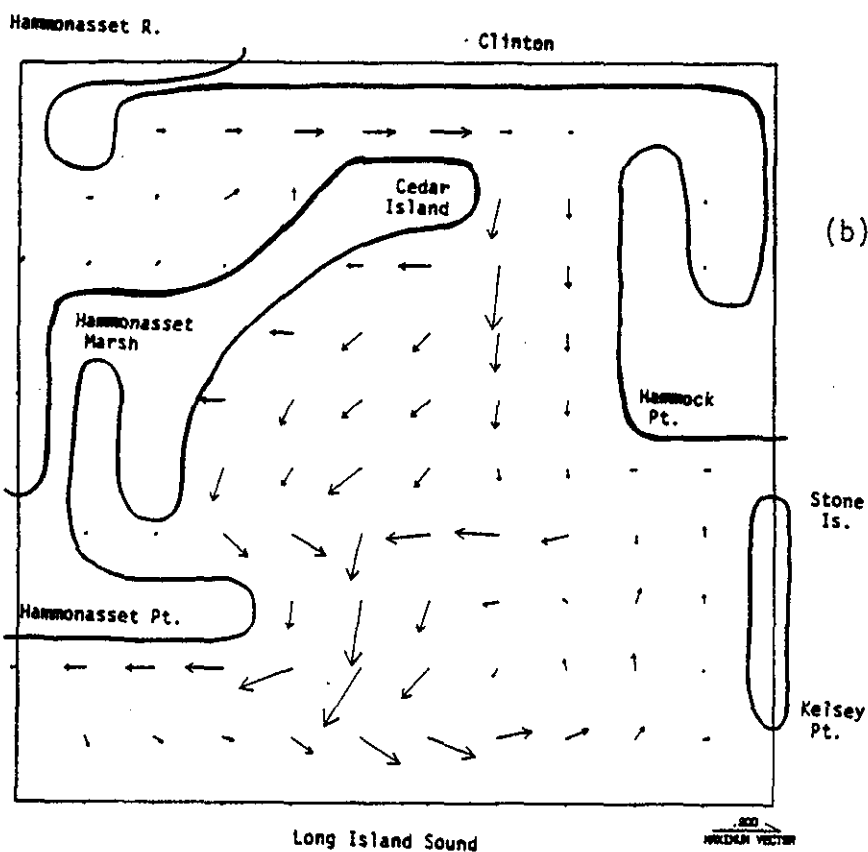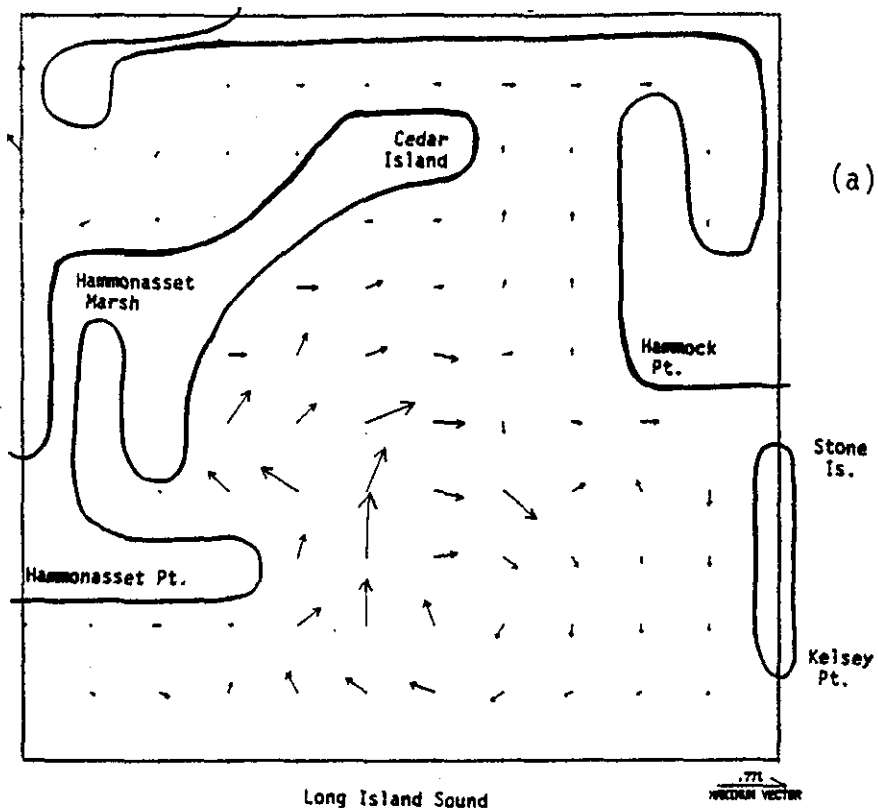data shown on
Figure 2-6).

Long Island Sound

Figure 3-4.   Simulated velocity vectors for Clinton Harbor -
verification period, NNE wind at 10 mph.

21

4.0 CIRCULATION IMPACTS OF PROPOSED DREDGED MATERIAL CONTAINMENT FACILITY

4.1 Review of Proposed DMCF Configurations

As noted in Section 1.1, the exact size and configuration of the proposed DMCF is not yet determined. Figure 1-1 shows two possible sizes and general configurations depending upon the amount of dredged material to be contained. Both the small and large DMCF configurations are evaluated to determine their impact on circulation and flushing characteristics in Clinton Harbor.

Figure 4-1 (a&b) shows the MSL depths and computational cell identifications for the smaller DMCF. Approximate area of the smaller DMCF is about 24 acres. The configuration differs from the model setup for existing conditions by assignment of additional non-flow cell flags and depths to the DMCF area consisting of 5 cells (29 acres).

Figure 4-2 (a&b) shows the MSL depths and computational cell identifications for the larger DMCF. Approximate area of the larger DMCF is about 75 acres. The model setup configuration differs from that for existing conditions by assignment of an additional 13 cells as non-flow cells (74 acres).

4.2 Assessment Criteria

Changes in circulation characteristics in Clinton Harbor due to DMCF placement can be assessed using a combination of factors, including:

o Graphical displays of tidal current velocity vectors for the harbor are useful for providing an overview of circulation characteristics.

o Current velocities at selected locations in the harbor may be increased or decreased. Differences in peak and average velocities are used for the assessment.

o Dispersion coefficients at selected locations are useful for comparison of net tidal circulation conditions and changes.

Dispersion is a generic term for transport and spread of material by tidal currents. The coefficient represents an integration of tidal current action over a tidal cycle.

Stable initial conditions were established for each assessment alternative and each run was conducted for a (simulated) period of 25 hours. The following simulation runs were conducted.

1. Existing Conditions

    (a) No wind.

    (b) SSW wind at 10 mph.

    (c) NNE wind at 10 mph.

a) Mean Sea Level Water Depths Throughout Bay

```
I/J   1    2    3    4    5    6    7    8    9   10   11   12
 1    0   30   15    0    0    9    9    9    9    9    9    9
 2   30   30   15    0    9    9    9    0    9    9    0    9
 3   30   25   15    0    9    0    0    0    9    9    9    9
 4   30   20   15    0    9    0    0    0    9    9    9    9
 5   30   20   10    2    3    0    0    0    0    9    9    0
 6   30   20   10    8    4    3    3    3    2    0    9    0
 7   30   20   10   10    6    3    3    3    2    0    9    0
 8   30   25   15   12    6    5    3    3    3    3    6    0
 9   30   25   20   12    8    5    1    1    1    1    6    0
10   35   30   20   12    8    6    0    0    0    0    9    0
11   40   30   15   10    8    8    0    0    9    9    9    0
12   40   30    0    0    0    8    0    0    0    0    0    0
```

b) Computational Cell Identifications

```
I/J   1    2    3    4    5    6    7    8    9   10   11   12
 1    1   27   27    1    1    6    6    6    2    2    6   12
 2   26    2   12    1    2    6   18    1    2   12    1   12
 3   26    2   12    1   12    1    1    1    2    2   12   12
 4   26    2   12    1   12    1    1    1    6    2   12   18
 5   26    2    2    2   12    1    1    1    1    6   12    1
 6   26    2    2    2   12    2    2    2   12    1   12    1
 7   26    2    2    2   12    2    2    2   12    1   12    1
 8   26    2    2    2    2    2    2    2    2    2   12    1
 9   26    2    2    2    2    2    6    6    6    6   12    1
10   26    2    2    2    2   12    1    1    1    1   12    1
11   26    2    6    6    6   12    1    1    6    6   18    1
12   26   25    1    1    1   25    1    1    1    1    1    1
```

Figure 4-1. Model setup for smaller DMCF.

23

a) Mean Sea Level Water Depths Throughout Bay

I/J	1	2	3	4	5	6	7	8	9	10	11	12
1	0	30	15	0	0	9	9	9	9	9	9	9
2	30	30	15	0	9	9	9	0	9	9	0	9
3	30	25	15	0	9	0	0	0	9	9	9	9
4	30	20	15	0	9	0	0	0	9	9	9	9
5	30	20	10	2	3	0	0	0	0	9	9	0
6	30	20	10	8	4	0	0	0	0	0	9	0
7	30	20	10	10	6	0	0	0	0	0	9	0
8	30	25	15	12	6	5	3	3	3	3	6	0
9	30	25	20	12	8	5	1	1	1	1	6	0
10	35	30	20	12	8	6	0	0	0	0	9	0
11	40	30	15	10	8	8	0	0	9	9	9	0
12	40	30	0	0	0	8	0	0	0	0	0	0

b) Computational Cell Identifications

I/J	1	2	3	4	5	6	7	8	9	10	11	12
1	1	27	27	1	1	6	6	6	2	2	6	12
2	26	2	12	1	2	6	18	1	2	12	1	12
3	26	2	12	1	12	1	1	1	2	2	12	12
4	26	2	12	1	12	1	1	1	6	2	12	18
5	26	2	2	2	12	1	1	1	1	6	12	1
6	26	2	2	2	12	1	1	1	1	1	12	1
7	26	2	2	2	12	1	1	1	1	1	12	1
8	26	2	2	2	2	2	2	2	2	2	12	1
9	26	2	2	2	2	2	6	6	6	6	12	1
10	26	2	2	2	2	12	1	1	1	1	12	1
11	26	2	6	6	6	12	1	1	6	6	18	1
12	26	25	1	1	1	25	1	1	1	1	1	1

Figure 4-2. Model setup for larger DMCF.

2. Small DMCF

    (a) No wind.

    (b) SSW wind at 10 mph.

    (c) NNE wind at 10 mph.

3. Large DMCF

    (a) No wind.

    (b) SSW wind at 10 mph.

    (c) NNE wind at 10 mph.

All runs were based on spring tide conditions. Trial simulations using mean tide conditions indicated little difference for spring tide conditions.

Station locations for which the assessment criteria data are tabulated are located on Figure 4-3 and include the following:

1.	WSOUND (I=3, J=2):	Located offshore near southwestern (top left) tidal boundary.
2.	CSOUND (I=7, J=2):	Located offshore near south central (bottom left) tidal boundary.
3.	ESOUND (I=11, J=2):	Located offshore near southeastern (bottom left) tidal boundary.
4.	W.ROCK (I=5, J=5):	Located on south (left) side of DMCF site.
5.	DMCF (I=5, J=7):	Located at center of DMCF site.
6.	CHANEL (I=8, J=8):	Located on east (bottom) side of DMCF site.
7.	CLINTN (I=8, J=10):	Located in main channel at mouth to inner harbor.
8.	WHEEL (I=8, J=5):	Located near Wheeler Rock.
9.	HAMOCK (I=9, J=6):	Located off Hammock Point.
10.	EBREAK (I=11, J=6):	Located near opening in breakwater east (bottom) of Clinton Harbor.

4.3 Assessment

Simulation runs based on input data conditions outlined above provide a good basis for assessment of possible changes in circulation characteristics attributable to naturally occurring wind conditions and the two DMCF configurations. Table 4-1 summarizes assessment attribute data extracted from simulation runs on maximum velocities, mean velocities, and dispersion coefficients for the three input wind conditions. The purpose of the assessment attribute array presentation is to provide DMCF placement and configuration within the context of naturally occurring variability due to wind direction and magnitude. Figures 4-4 through 4-12 present graphic plots of velocity vectors for the assessment conditions.

```
I/J   1   2   3   4   5   6   7   8   9  10  11  12
 1    1  27  27   1   1   6   6   6   2   2   6  12
 2   26   2  12   1  12   6  13   1   2  12   1  12
 3   26   A  12   1  12   1   1   1   2   2  12  12
 4   26   2  12   1   2   2  12   1   6   2  12   3
 5   26   2   2   2   D   2   E  12   1   6  12   1
 6   26   2   2   2   2   2   2   2  12   1  12   1
 7   26   B   2   2   2   2   2  12   1  12   1
 8   26   2   2   2   H   2   2   F   2   G  12   1
 9   26   2   2   2   2   I   6   6   6   6  12   1
10   26   2   2   2   2  12   1   1   1   1  12   1
11   26   C   6   6   6   J   1   1   6   6  13   1
12   26  25   1   1   1  25   1   1   1   1   1   1
```

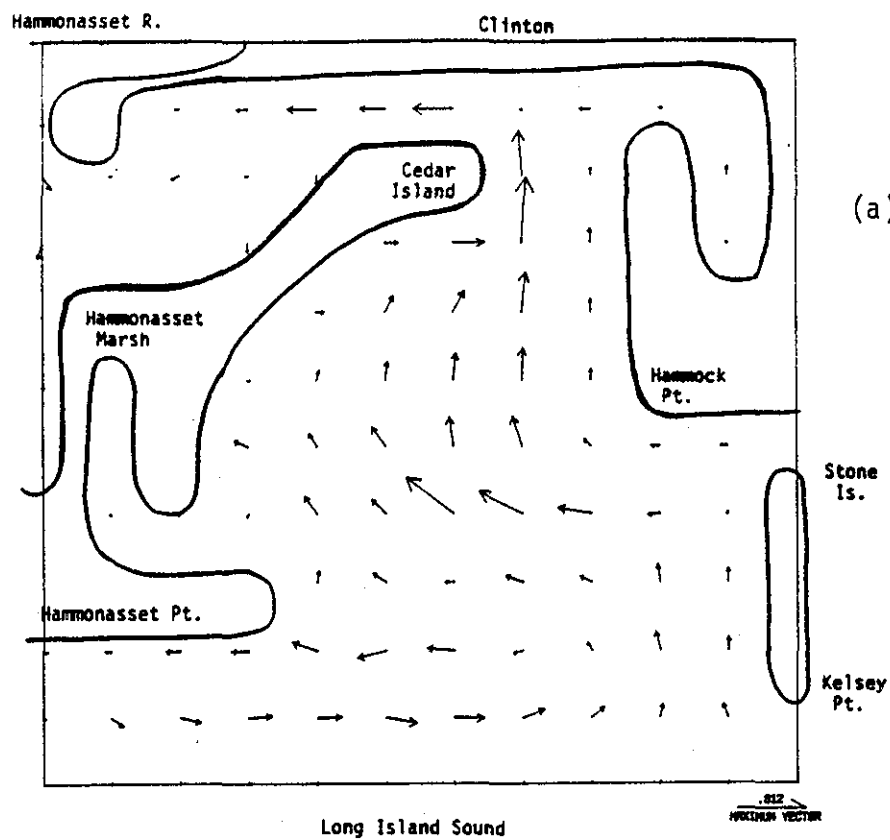|			
(A)	WSOUND	(I=3 , J= 2)
(B)	CSOUND	(I=7 , J= 2)
(C)	ESOUND	(I=11, J= 2)
(D)	W.ROCK	(I-5 , J= 5)
(E)	DMCF	(I=5 , J= 7)
(F)	CHANEL	(I=8 , J= 8)
(G)	CLINTN	(I=8 , J=10)
(H)	WHEEL	(I=8 , J= 5)
(I)	HAMOCK	(I=9 , J= 6)
(J)	EBREAK	(I=11, J= 6)

Figure 4-3. Location of index stations.

TABLE 4-1

SIMULATION DATA RESULTS FROM CLINTON HARBOR

Station	Max. Velocity [1]			Mean Velocity [1]			Dispersion Coef. [2]		
	Existing Cond.	Small DMCF	Large DMCF	Existing Cond.	Small DMCF	Large DMCF	Existing Cond.	Small DMCF	Large DMCF
Wind = 0									
1. WSOUND	0.23	0.16	0.15	0.16	0.08	0.08	360	70	70
2. CSOUND	0.45	0.51	0.52	0.35	0.37	0.37	1200	1300	1300
3. ESOUND	0.17	0.14	0.12	0.09	0.07	0.07	110	56	30
4. W.ROCK	0.31	0.17	0.18	0.18	0.07	0.06	250	44	40
5. DMCF	0.17	--	--	0.10	--	--	125	--	--
6. CHANEL	0.49	0.69	1.20	0.30	0.38	0.61	1400	1900	4400
7. CLINTN	0.85	0.82	1.00	0.52	0.53	0.51	1750	1900	1700
8. WHEEL	0.83	0.93	0.87	0.53	0.51	0.45	1700	2400	1500
9. HAMOCK	0.24	0.36	0.44	0.11	0.14	0.15	100	330	260
10. EBREAK	0.11	0.11	0.11	0.07	0.06	0.06	50	65	40
Wind = 10 mph (SSW)									
1. WSOUND	0.23	0.18	0.17	0.13	0.11	0.11	240	130	130
2. CSOUND	0.31	0.75	0.75	0.20	0.65	0.66	420	3600	3600
3. ESOUND	0.15	0.16	0.14	0.08	0.08	0.08	80	50	50
4. W.ROCK	0.55	0.37	0.38	0.31	0.18	0.19	730	250	250
5. DMCF	0.29	--	--	0.17	--	--	290	--	--
6. CHANEL	0.59	0.75	1.21	0.34	0.42	0.61	1470	2000	4400
7. CLINTN	0.92	0.88	1.06	0.53	0.54	0.52	1800	2000	1700
8. WHEEL	0.87	1.10	1.08	0.46	0.78	0.76	1400	4200	3900
9. HAMOCK	0.37	0.44	0.50	0.21	0.19	0.21	300	400	300
10. EBREAK	0.13	0.13	0.14	0.09	0.07	0.07	60	70	40
Wind = 10 mph (NNE)									
1. WSOUND	0.25	0.14	0.13	0.18	0.06	0.06	460	45	40
2. CSOUND	0.79	0.41	0.41	0.67	0.22	0.22	3700	520	530
3. ESOUND	0.18	0.15	0.14	0.12	0.09	0.08	230	95	530
4. W.ROCK	0.67	0.27	0.28	0.30	0.15	0.14	520	230	200
5. DMCF	0.36	--	--	0.22	--	--	320	--	--
6. CHANEL	0.49	0.63	1.18	0.22	0.37	0.62	1400	1800	4400
7. CLINTN	0.85	0.84	0.95	0.52	0.53	0.51	1700	1900	1700
8. WHEEL	1.1	0.90	0.84	0.80	0.60	0.56	5200	2800	2000
9. HAMOCK	0.27	0.30	0.38	0.15	0.16	0.18	220	360	300
10. EBREAK	0.12	0.13	0.11	0.07	0.06	0.06	60	65	40

(1) Ft/sec.   (2) Ft^2/sec.
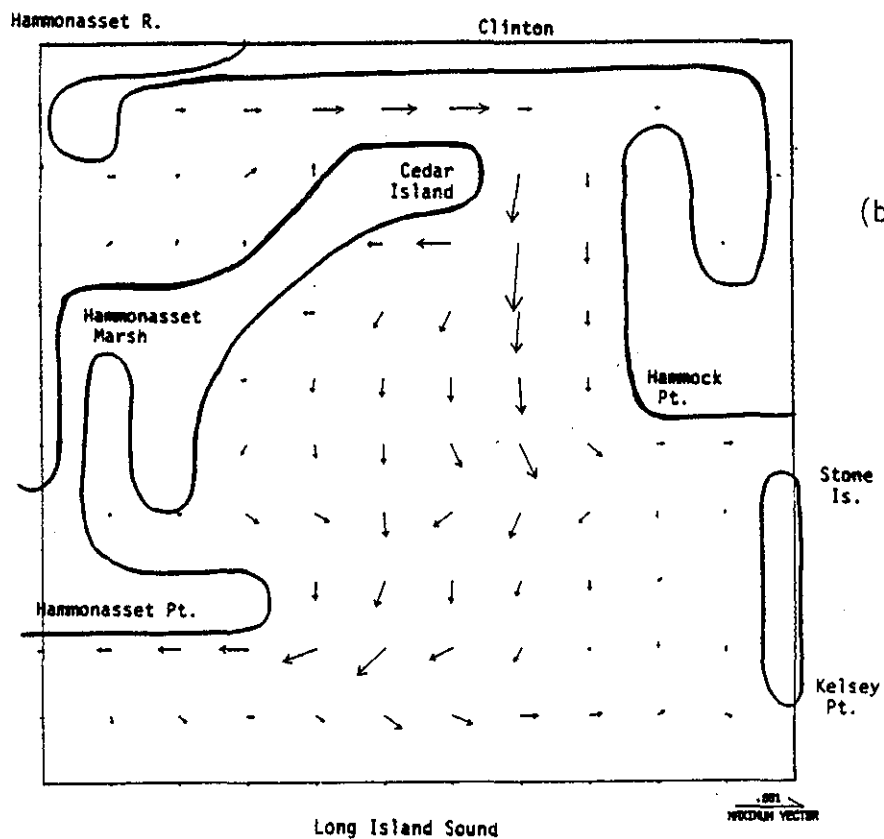
Figure 4-4.   Simulated velocity vectors for Clinton Harbor.
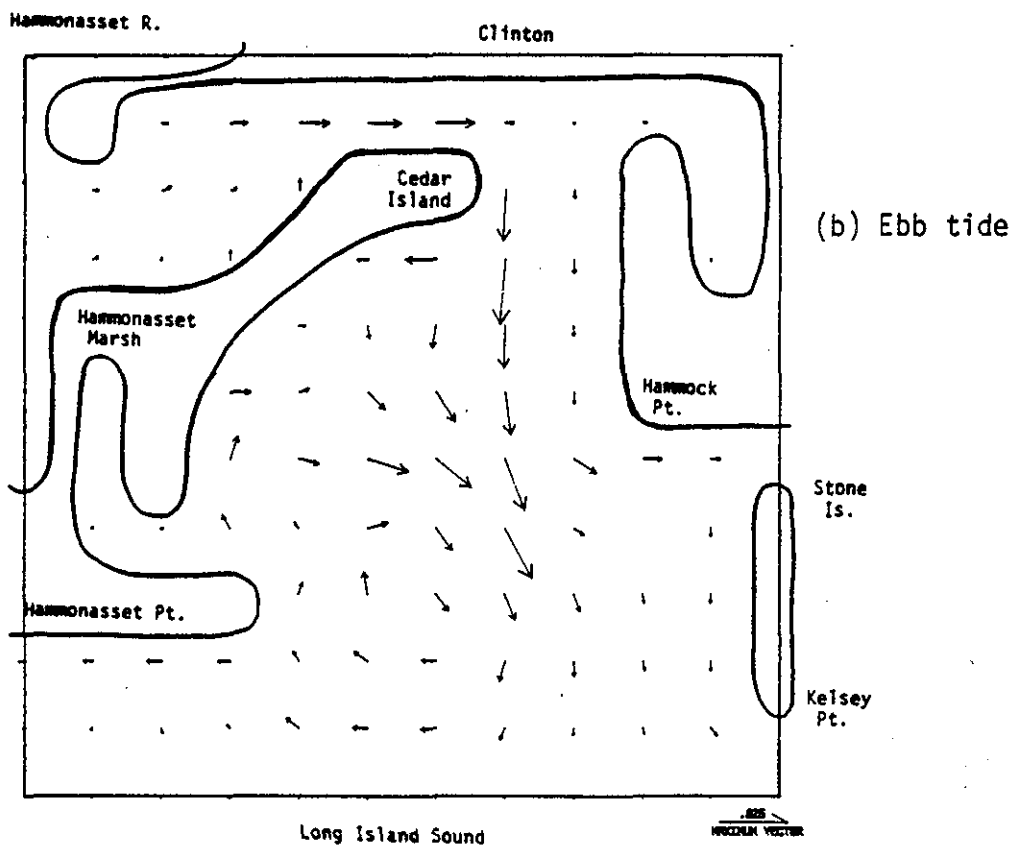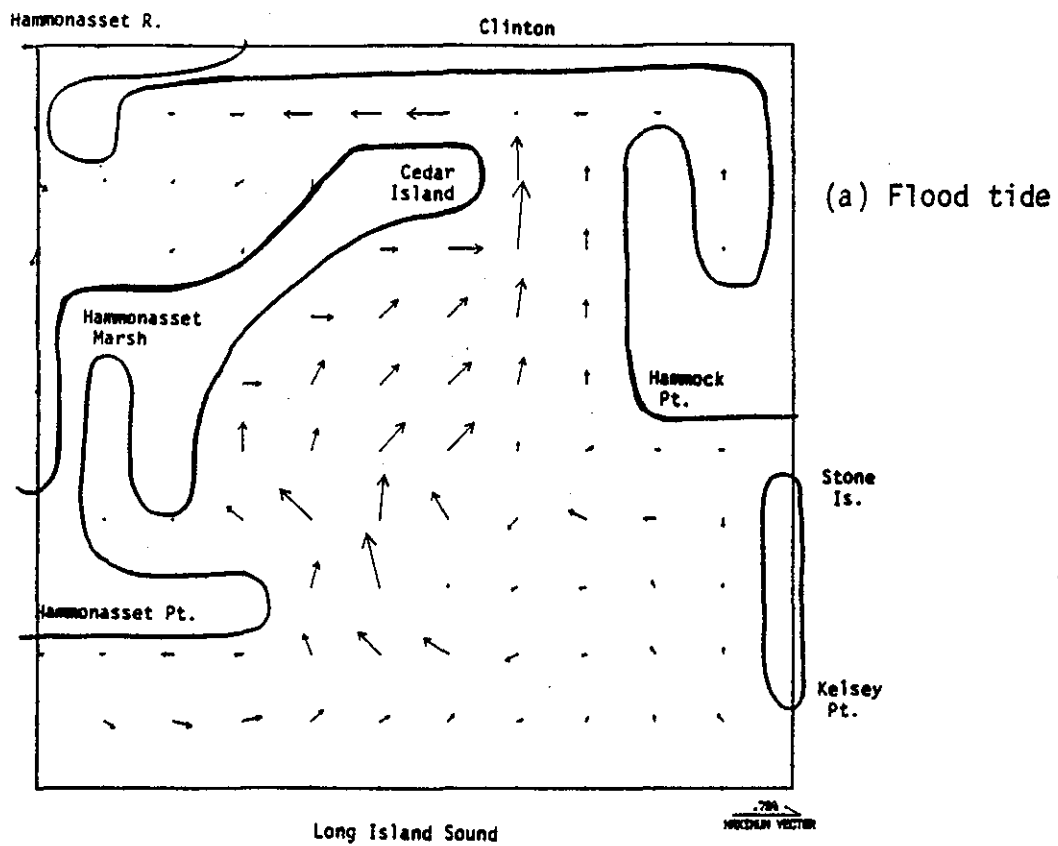Existing conditions, no wind.

Figure 4-5. Simulated velocity vectors for Clinton Harbor.
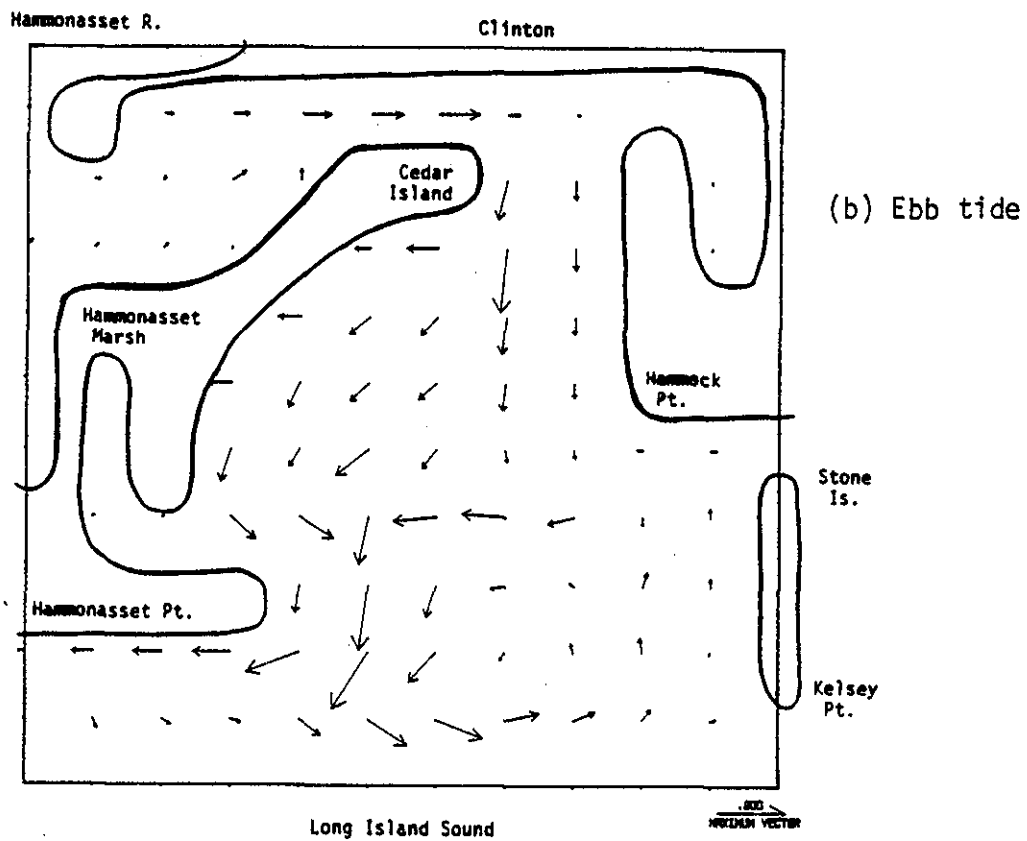Existing conditions, SSW wind = 10 mph.

29

Figure 4-6. Simulated velocity vectors for Clinton Harbor.
Existing conditions, NNE wind = 10 mph.
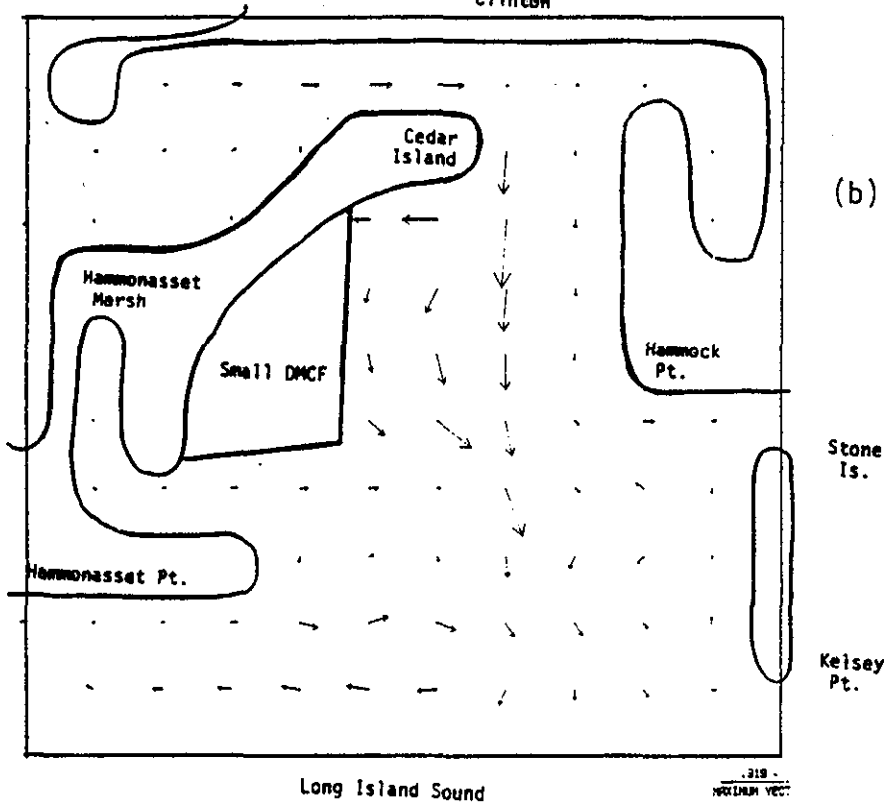
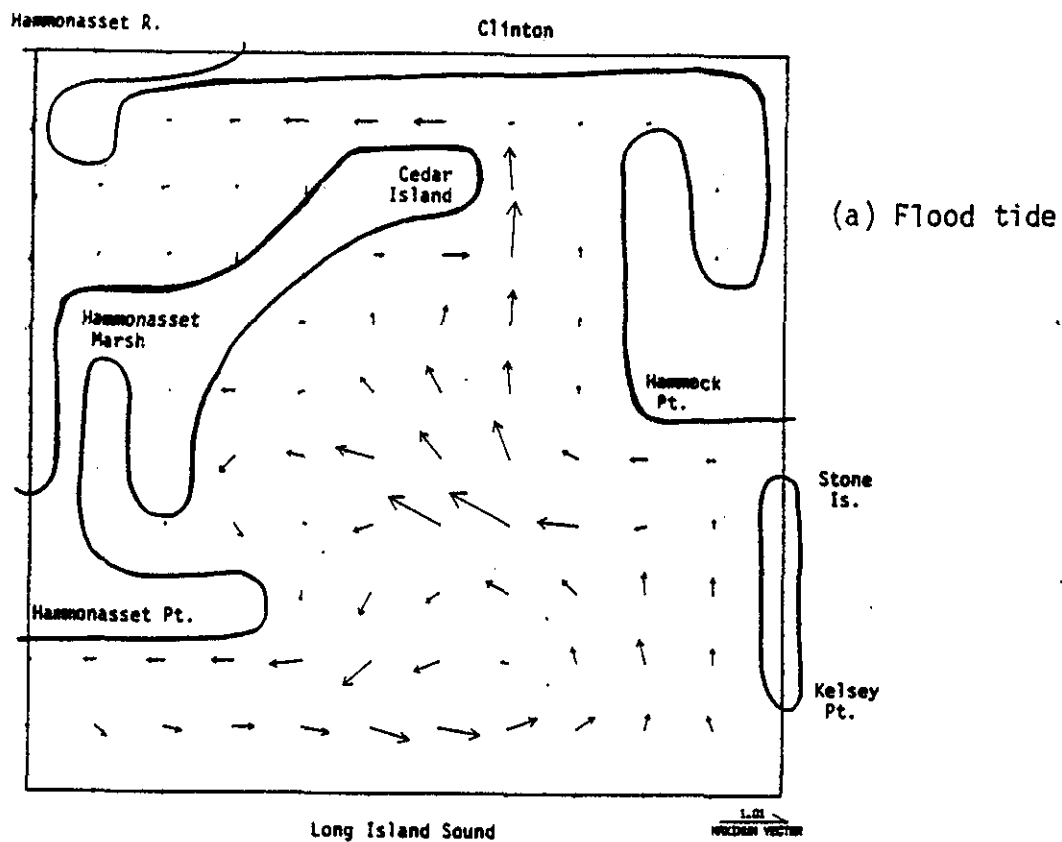**(a) Flood tide**

(b) Ebb tide

Figure 4-7. Simulated velocity vectors for Clinton Harbor. Small DMCF, no wind.
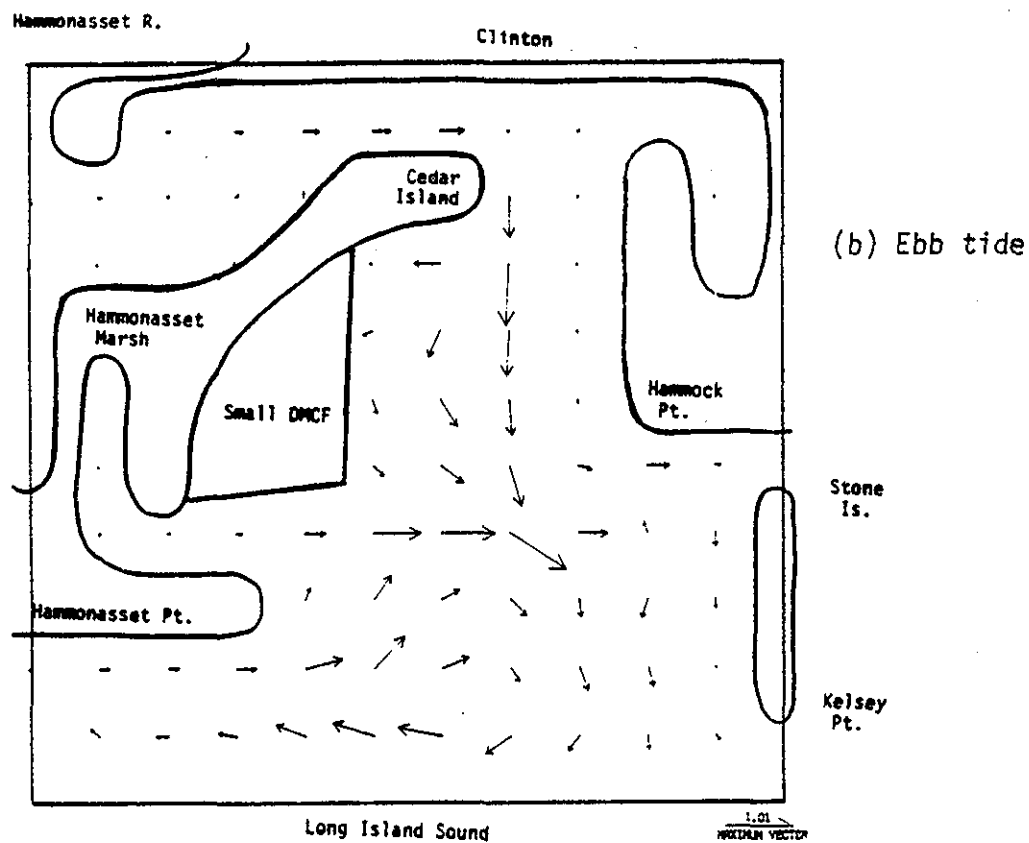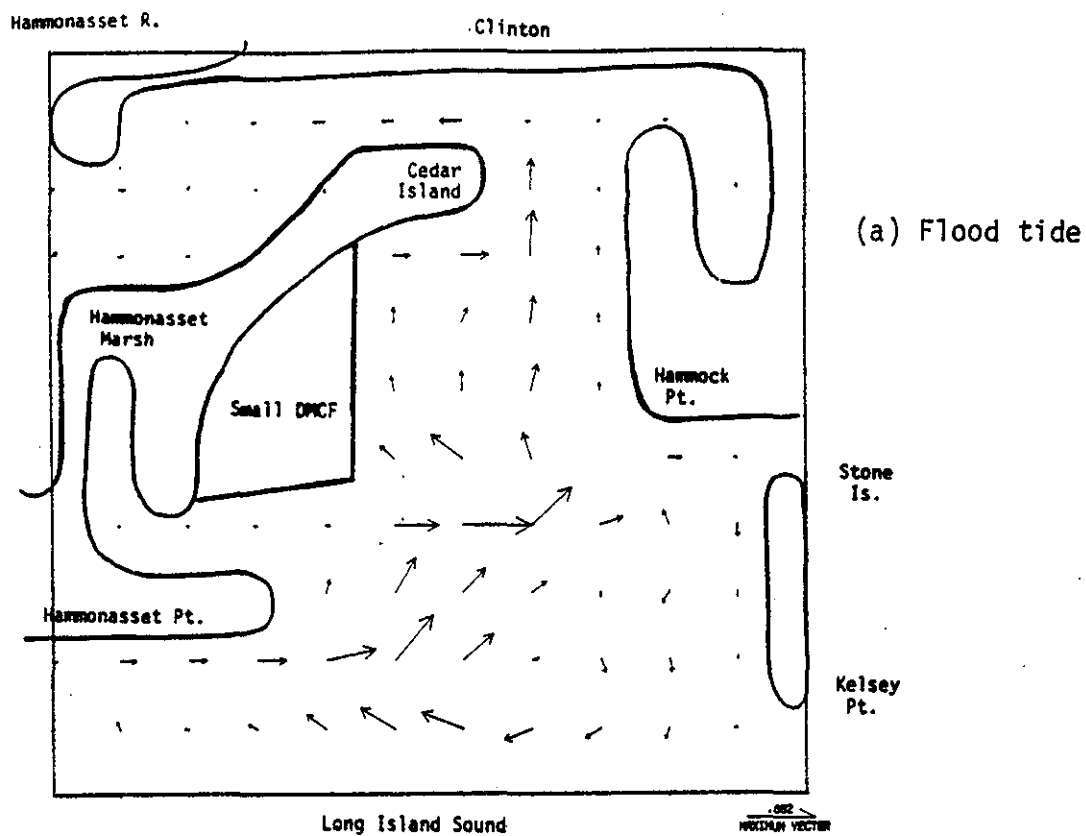
Figure 4-8. Simulated velocity vectors for Clinton Harbor.
Small DMCF, SSW wind = 10 mph.
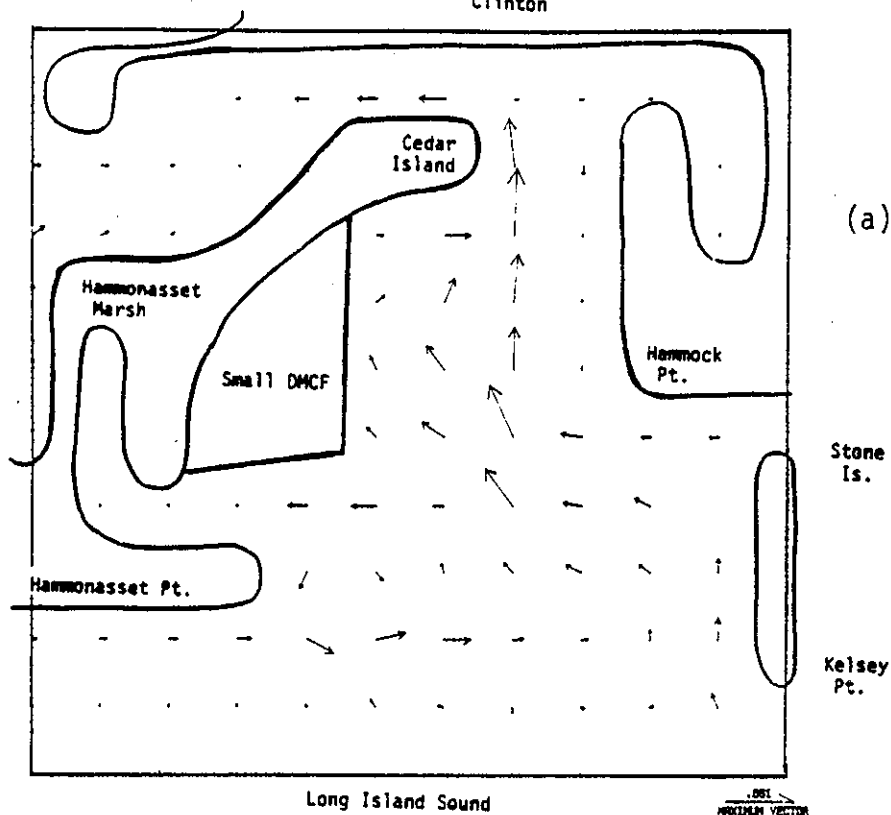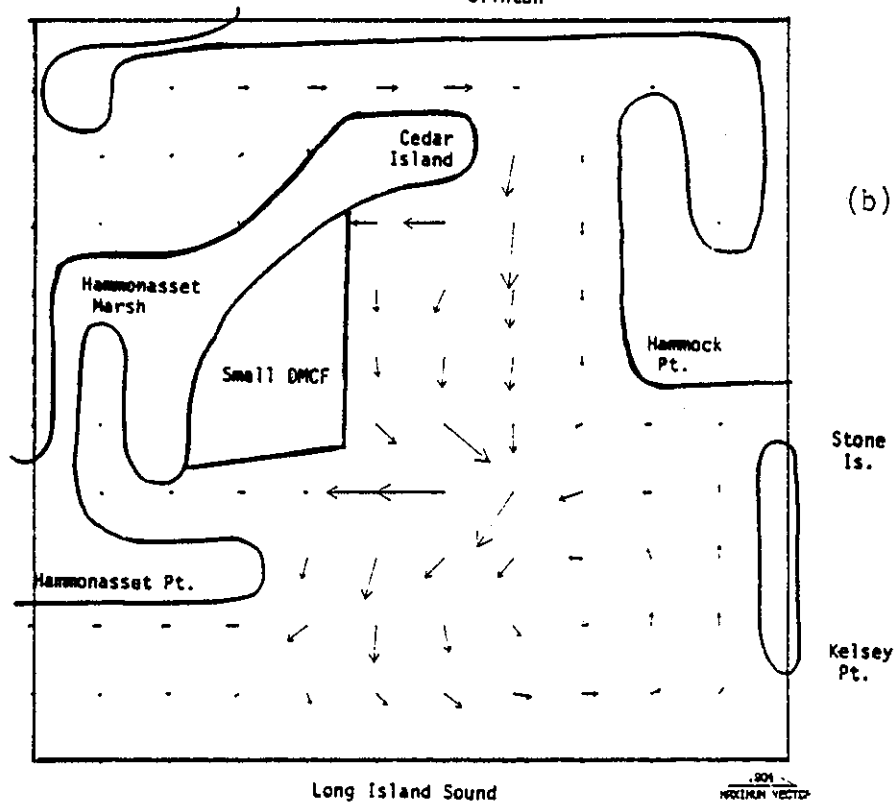
Figure 4-9. Simulated velocity vectors for Clinton Harbor.
Small DMCF, NNE wind = 10 mph.

Figure 4-10.   Simulated velocity vectors for Clinton Harbor.
Large DMCF, no wind.
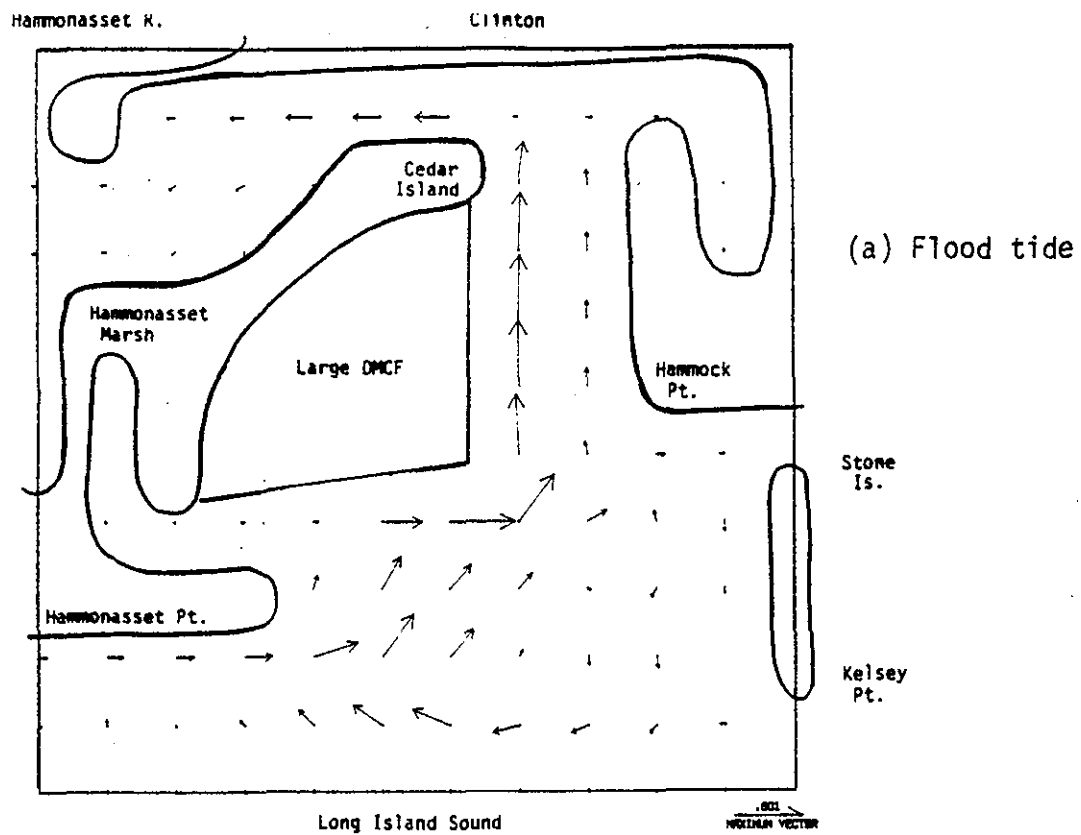
Figure 4-11. Simulated velocity vectors for Clinton Harbor.
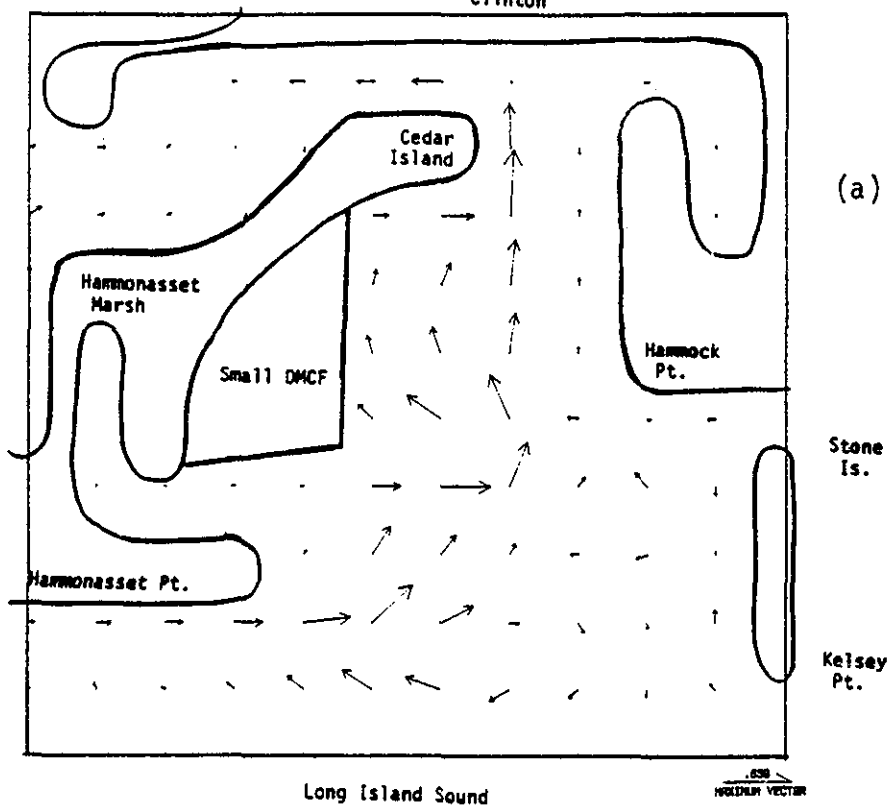Large DMCF, SSW wind = 10 mph.
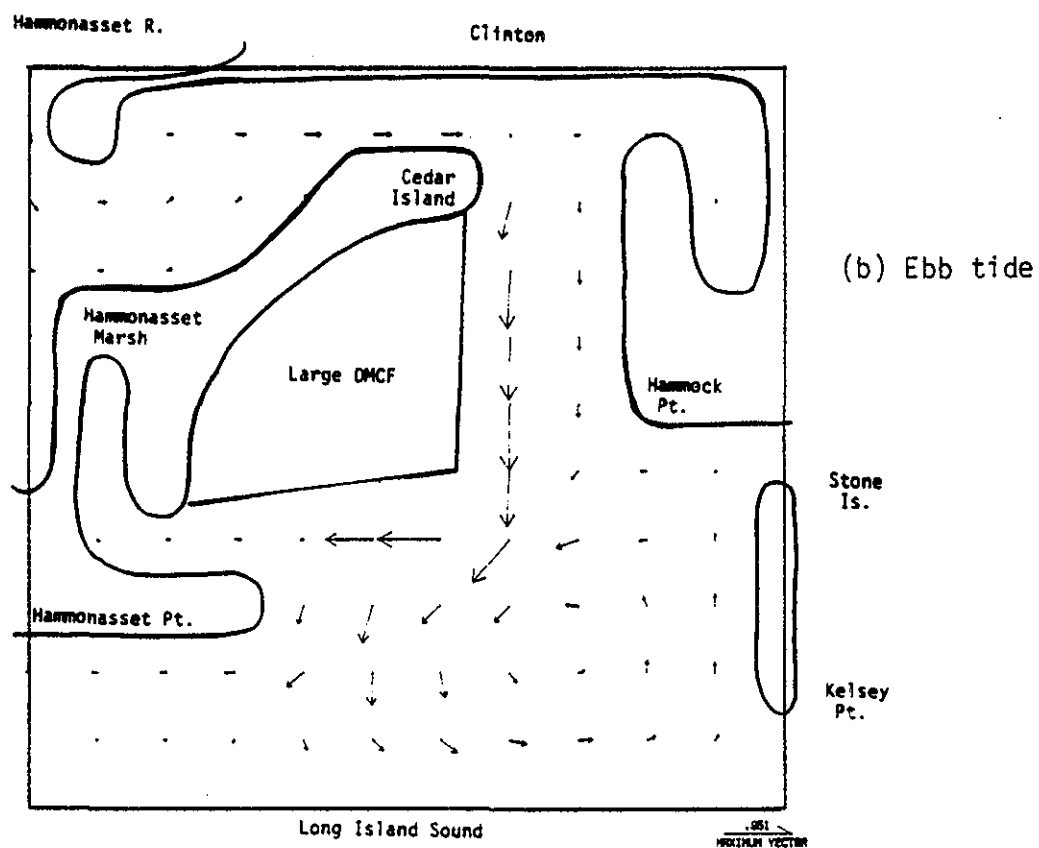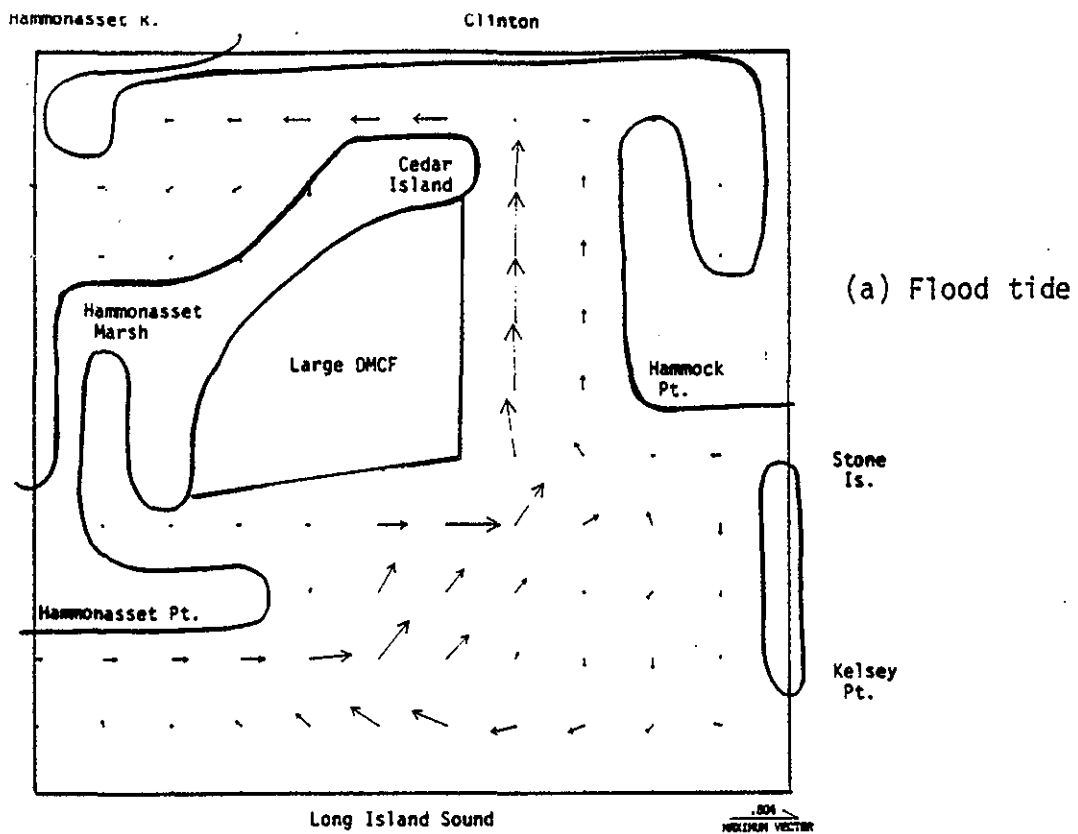
Figure 4-12.   Simulated velocity vectors for Clinton Harbor.
Large DMCF, NNE wind = 10 mph.

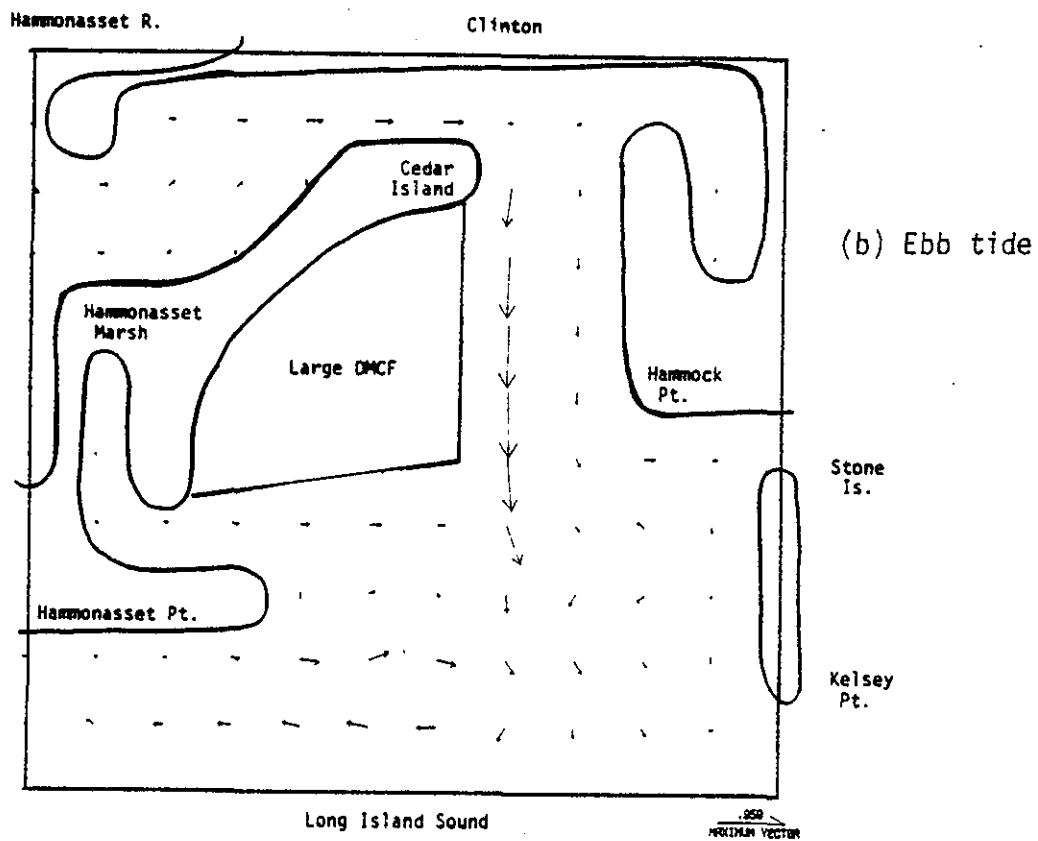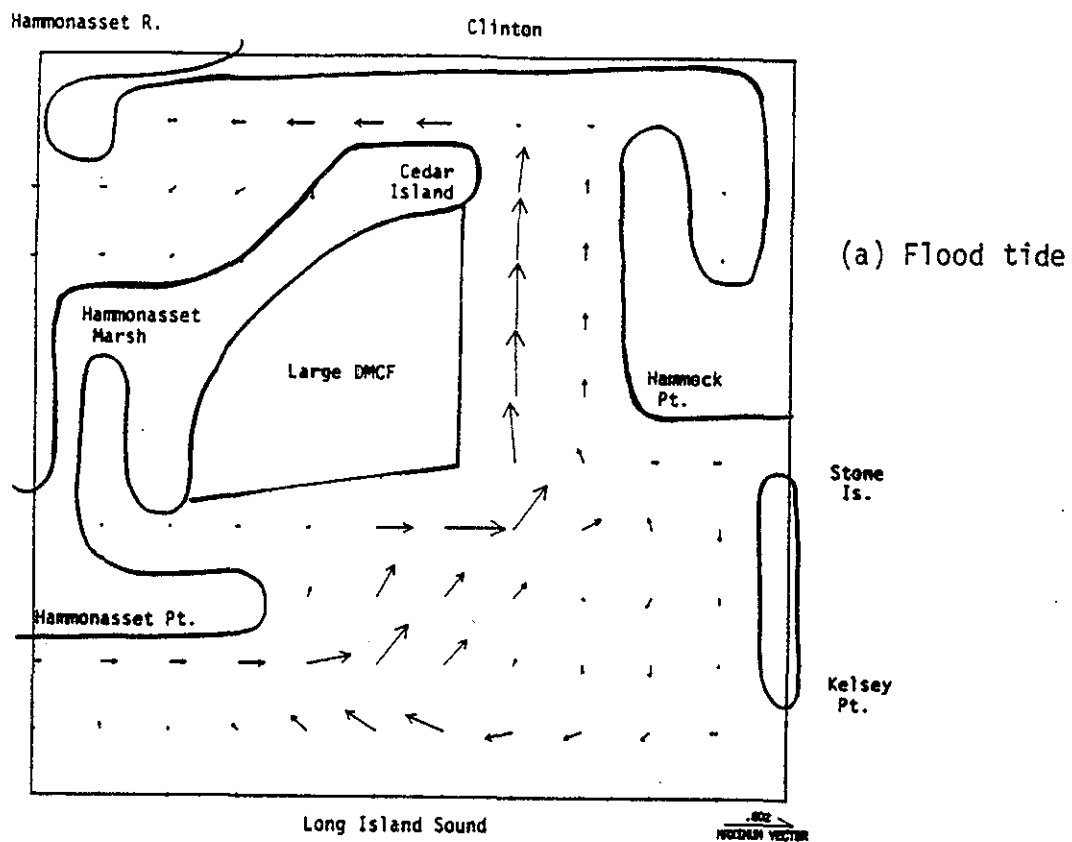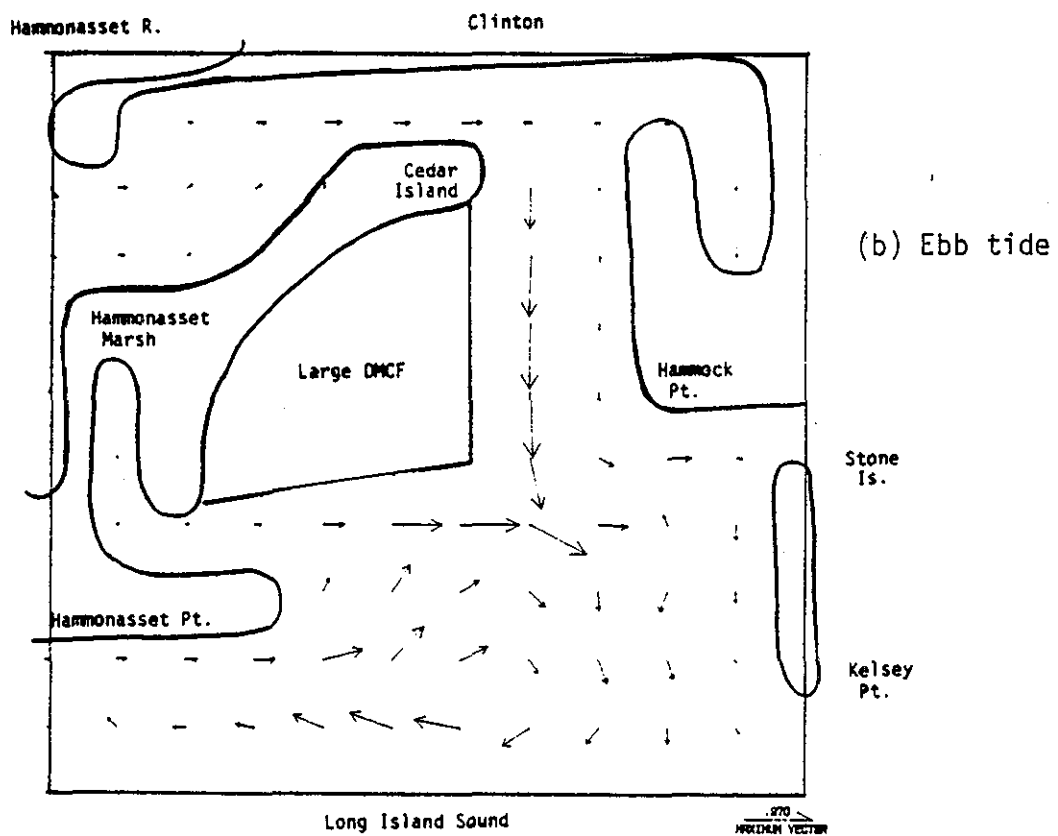The study area can be divided into three subareas, including:

o Outer harbor represented by stations WSOUND, CSOUND, ESOUND, HAMOCK, and EBREAK.

o Middle harbor, represented by stations W.ROCK, DMCF, CHANEL, and WHEEL.

o Inner harbor represented by the station at CLINTN.

4.3.1 Outer Harbor

The outer harbor is dominated by input tidal boundary conditions for Long Island Sound imposed on the model. No prototype data were obtained for this section of the harbor, so simulated current directions may not represent actual existing conditions.

The influence of wind is quite pronounced as a circulation gyre is established which rotates in different directions depending on wind direction (see Figures 4-4, 4-5, 4-6). The gyre is formed due to limits on circulation caused by the eastern breakwater and depth variations. There is little (simulated) flow through the breakwater opening (EBREAK) relative to flow into and from the middle and inner harbor.

There are no discernable changes in circulation characteristics in the outer harbor attributable to DMCF placement and configuration.

4.3.2 Middle Harbor

The middle harbor includes the DMCF site and shows the greatest changes in circulation due to DMCF placement and configuration. Simulation results for this section of Clinton Harbor are considered most valid, as this is the section where prototype data were obtained and model calibration/verification established.

The influence of wind is considerable as evidence by the drogue survey (Figures 2-3 to 2-6) and the simulation model results (Figures 4-5 and 4-6). With a southerly wind (Figure 4-5), flood tide currents align with the wind and flow past West Rock while ebb tide currents, flowing counter to the wind, are forced to the east when exiting to the outer harbor past Wheeler Rock. With a northerly wind, ebb tide currents align with the wind and flow over the West Rock area (Figures 4-6(b) and 2-6). Numerical data presented in Table 4-1 indicate the following variations at the index stations can be attributed to wind direction:

W.ROCK

- 2X variation in maximum velocity.

- 2X variation in mean velocity.

- 2X variation in dispersion coefficient.

DMCF

- 2X variation in maximum velocity.

- 2X variation in mean velocity.

- 2X variation in dispersion coefficient.

CHANEL

- Small change in maximum velocity.

- 1.5X variation in mean velocity.

- Negligible change in dispersion coefficient.

WHEEL

- Small change in maximum velocity.

- 1.5X change in mean velocity.

- 2X change in dispersion coefficient.

In general, then, the largest variations due to wind occur near West Rock and the DMCF site on the west side of the middle harbor.

Placement of a DMCF in the middle harbor has a significant influence on circulation patterns and velocities. Data presented in Table 4-1 suggest the following changes at the index stations can be attributed to DMCF placement and configuration:

W.ROCK

- 1/2X decrease in maximum velocity for both small and large DMCF.

- 1/2X decrease in mean velocity for both small and large DMCF.

- 1/2 to 1/7 decrease in dispersion coefficient for both small and large DMCF.

DMCF

- Site to be filled so no flow simulated by model. New marsh development will require channels into DMCF to permit tidal flow exchange (not represented in model).

CHANEL

- 1.5X increase in maximum velocity for small DMCF, 2X or greater increase for large DMCF.

- 1.5X increase in mean velocity for small DMCF, 2X to 3X increase for large DMCF.

- 1.5X increase in dispersion coefficient for small DMCF, 3X increase for large DMCF.

WHEEL
- Little or no change in maximum velocity for either small or large DMCF.
- Little or no change in mean velocity for either small or large DMCF.
- Little or no change in dispersion coefficient for either small or large DMCF.

Other than at the DMCF site, two areas of potential circulation impact in the middle harbor are identified. Near West Rock, current velocities and overall circulation are predicted to be reduced due to blockage of tidal flow by the DMCF. Constriction of flows by the DMCF toward the eastern section of the middle harbor would increase flow velocities in that section. The degree of velocity increase appears to be generally proportional to the degree of constriction.

4.3.3 Inner Harbor

The inner harbor, as represented by the index station CLINTN located at the mouth, is influenced only to a small degree by simulated variations in wind direction or by DMCF placement in the middle harbor. Of course, wind surge conditions resulting from protracted and strong southerly winds over Long Island Sound would be expected to increase the tidal prism passing into and from the inner harbor estuary, but these conditions are not evaluated by the simulation approach.

Placement of the larger DMCF does seem to increase (simulated) maximum velocities past the CLINTN index site by approximately 20 percent. However, there is no change in maximum velocity for the smaller DMCF. Also, there are no predicted changes in mean velocities or dispersion coefficients for either of the DMCF configurations. In all instances, the tidal prism flowing to and from the inner harbor estuary is passed with no apparent differences from existing conditions.

4.4 Conclusions

Review of results of the prototype data collection activities in the middle portion of Clinton Harbor indicates that circulation characteristics are strongly influenced by wind direction. Winds from the south and west tend to cause dominant current flows toward the eastern portion of the middle harbor and Wheeler Rock. Winds from the north and east tend to cause dominant current flows further to the west over the proposed DMCF site and the West Rock area.

A mathematical model which simulates tidally induced current flows in the harbor is used to assess potential changes in existing circultion characteristics due to alternative DMCF configuration in the middle harbor. The model is calibrated and verified using prototype data obtained by current meter measurements and the drogue survey. It is concluded that the model adequately represents existing circulation characteristics based on statistical comparison of simulated versus prototype maximum and mean velocities and graphical display of current velocities and directions

It is emphasized that the mathematical model does not incorporate representations for wave-induced turbulence and mixing--factors which are believed important in the overall water energy regime in the vicinity of the proposed DMCF site. Conclusions on circulation changes potentially resulting from DMCF placement in the middle harbor would be conditioned by this limitation of the mathematical simulation model--particularly where an energy reduction is projected.

Field data collected for the middle portion of Clinton Harbor, in or near where the proposed DMCF is to be located on the western side, indicate that tidal waters comprising the tidal prism flowing to and from the inner harbor and associated marshlands routinely pass over the DMCF. That is, tidal flows are not restricted to the Federal navigation channel on the eastern side of the middle harbor,

Simulations of tidal circulation indicate that placement of a DMCF of the sizes considered will tend to restrict flows more toward the eastern portion of the middle harbor and increase peak and maximum velocities in that area. The degree of increase is generally proportional to the size of the DMCF. On the south side of the DMCF site, near West Rock, material placement will block tidal circulation which formerly passed over the DMCF site.

Data developed on sediment stability by Marine Surveys, Inc. (Section III) coupled with current predictions indicate the potential for widespread sediment transport in the middle harbor should the DMCF be constructed. Wave refraction/diffraction effects have not been evaluated and could have an important bearing on this question. Some Long Island Sound wave data currently exist and new wave data are being collected which could be used to model wave refraction/diffraction patterns. Such analysis, if coupled with the developed tidal hydrodynamic model, could provide an analysis base appropriate for predicting probable changes in the total water energy and consequent sediment and transport due to DMCF placement.

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SECTION III

REMOTS^{TM} SURVEY
OF CLINTON HARBOR, CT

Marine Surveys, Inc.

TABLE OF CONTENTS

INTRODUCTION

A REMOTS benthic survey was conducted in Clinton Harbor, Connecticut, on September 2-3, 1981, and October 26-27, 1981. Station locations are given in Figure 1. Field surveys were carried out in conjunction with Taxon, Inc., as part of an environmental baseline and assessment study to evaluate Clinton Harbor as a DMCF site.

SEDIMENTARY AND BIOLOGICAL HABITAT PARAMETERS

Methods

The areal distribution of sediment types is shown in Figure 2A and 2B. The grain size data were obtained directly from the sediment-profile photographs of the sampling stations, by comparing the textures observed in these photographs with a set of photographic grain-size standards (prepared from sediments sieved to Udden-Wentworth grades). Optical resolution is limited to grain sizes $> 63\mu$ and can be reasonably characterized within 1 phi (ϕ) size. The grain size range and major mode(s) were estimated from each station photo-replicate, and plotted as silt, very fine sand (vfs), fine sand (fs), medium sand (ms), coarse sand (cs), very coarse sand (vcs), and granule. The five grain-size groupings (I through IV, and IV/I) mapped in Figure 2A-B, were delineated by "best fit" contouring of the Udden-Wentworth grades into a workable sedimentary facies pattern.

The sediment-profile images can also provide information about biological components (see Rhoads & Germano, 1982). These data are most accurate for epifaunal and semi-infaunal species which are readily visible in the photographs. Infaunal taxa are less accurately characterized and, in many cases, their presence can only be deduced from the presence of subsurface feeding "pockets."

In addition to identifying epifaunal and semi-infaunal taxa, we can sometimes identify the stage of faunal succession, map the depth of the redox potential discontinuity (RPD), and presence of sediment methane, along with the presence or absence of dissolved oxygen over the bottom. These variables have been combined into a habitat index by summing the the following values:
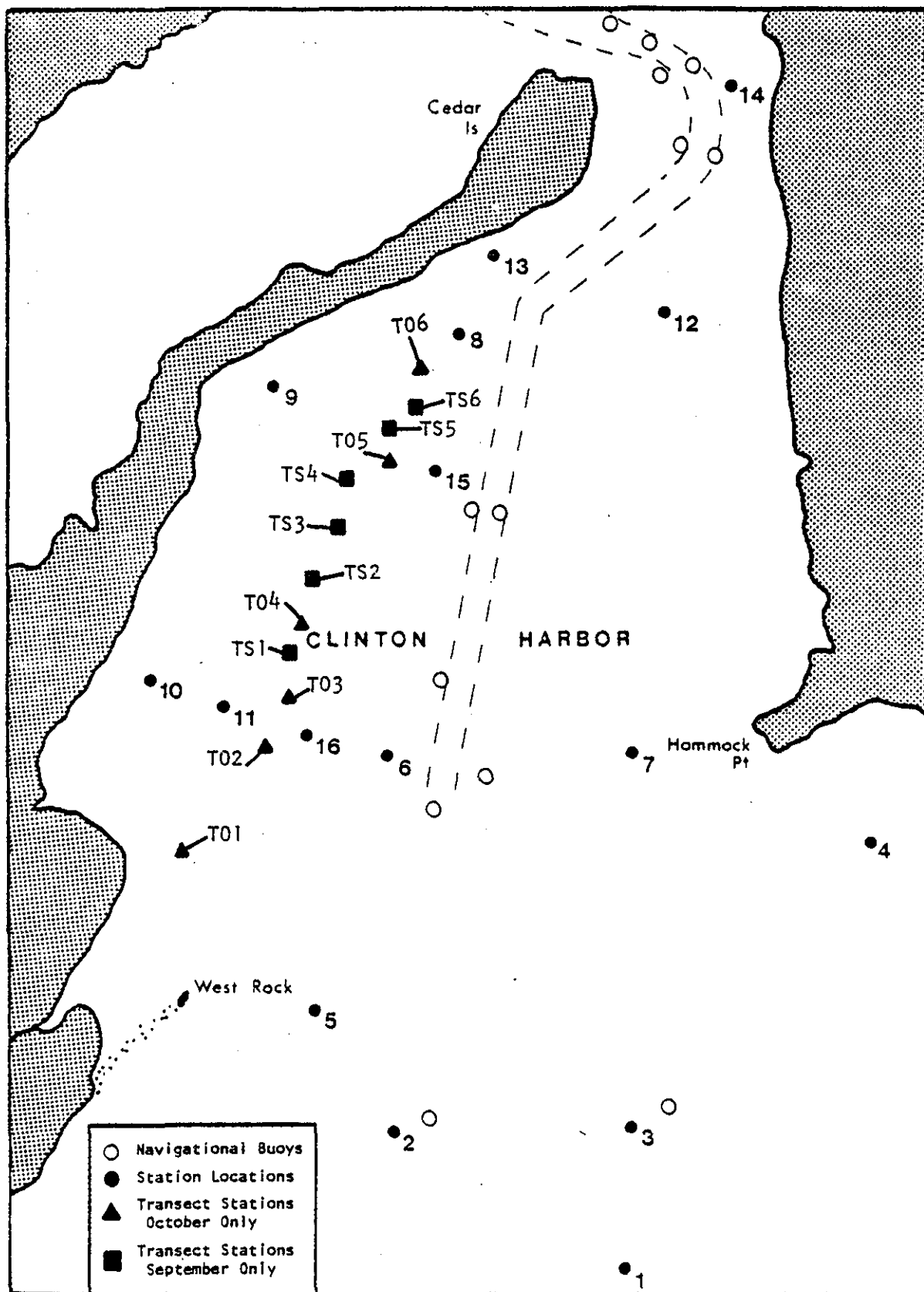
Figure 1. Station locations, September-October 1981.
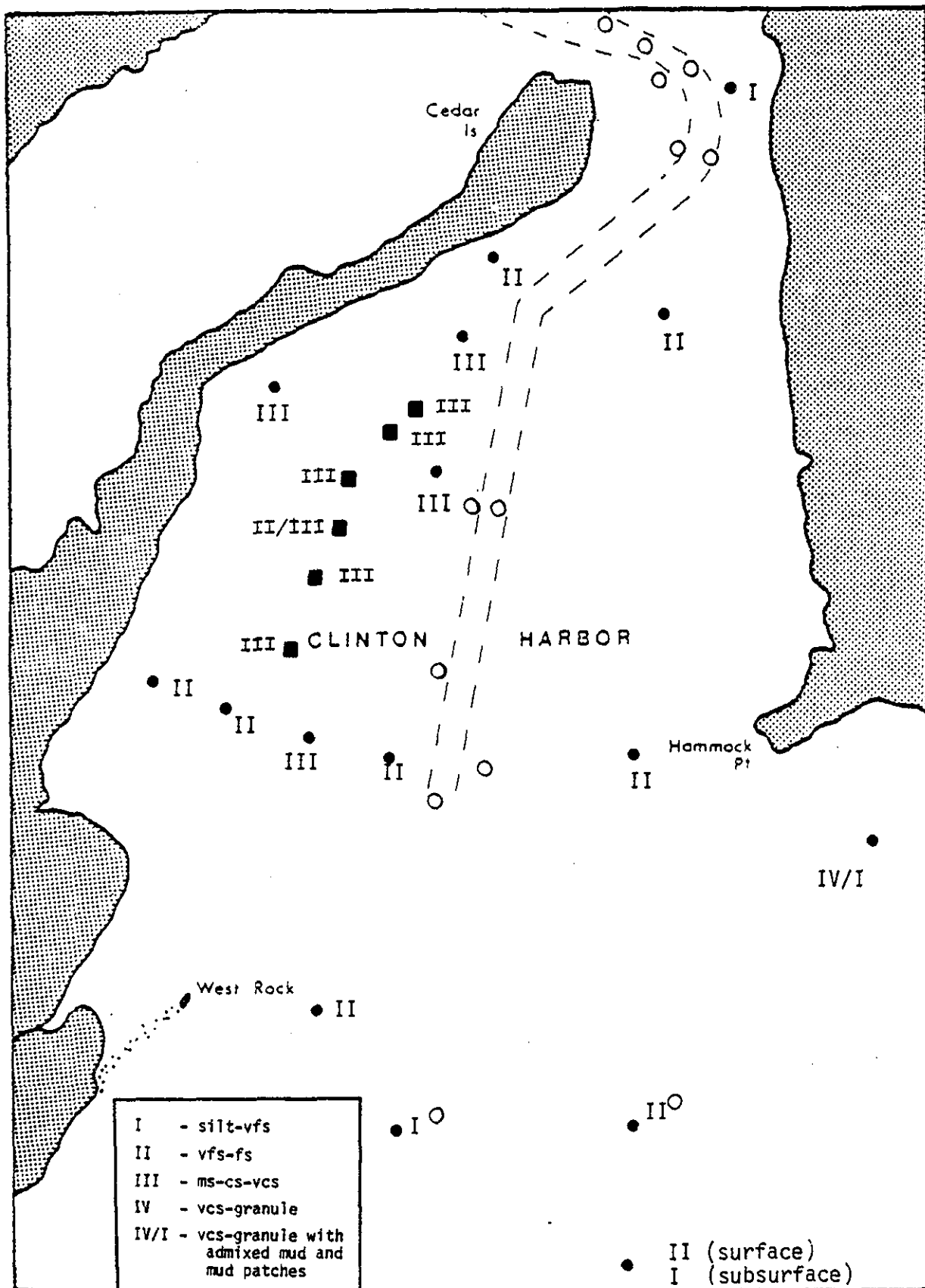
Figure 2A. Station values for grain size groupings for September 1981.

The legend reads:

I   – silt–vfs
II   – vfs–fs
III   – ms–cs–vcs
IV   – vcs–granule
IV/I   – vcs–granule with admixed mud and mud patches

II (surface)
I (subsurface)

Map labels: Cedar Is, CLINTON HARBOR, Hammock Pt, West Rock
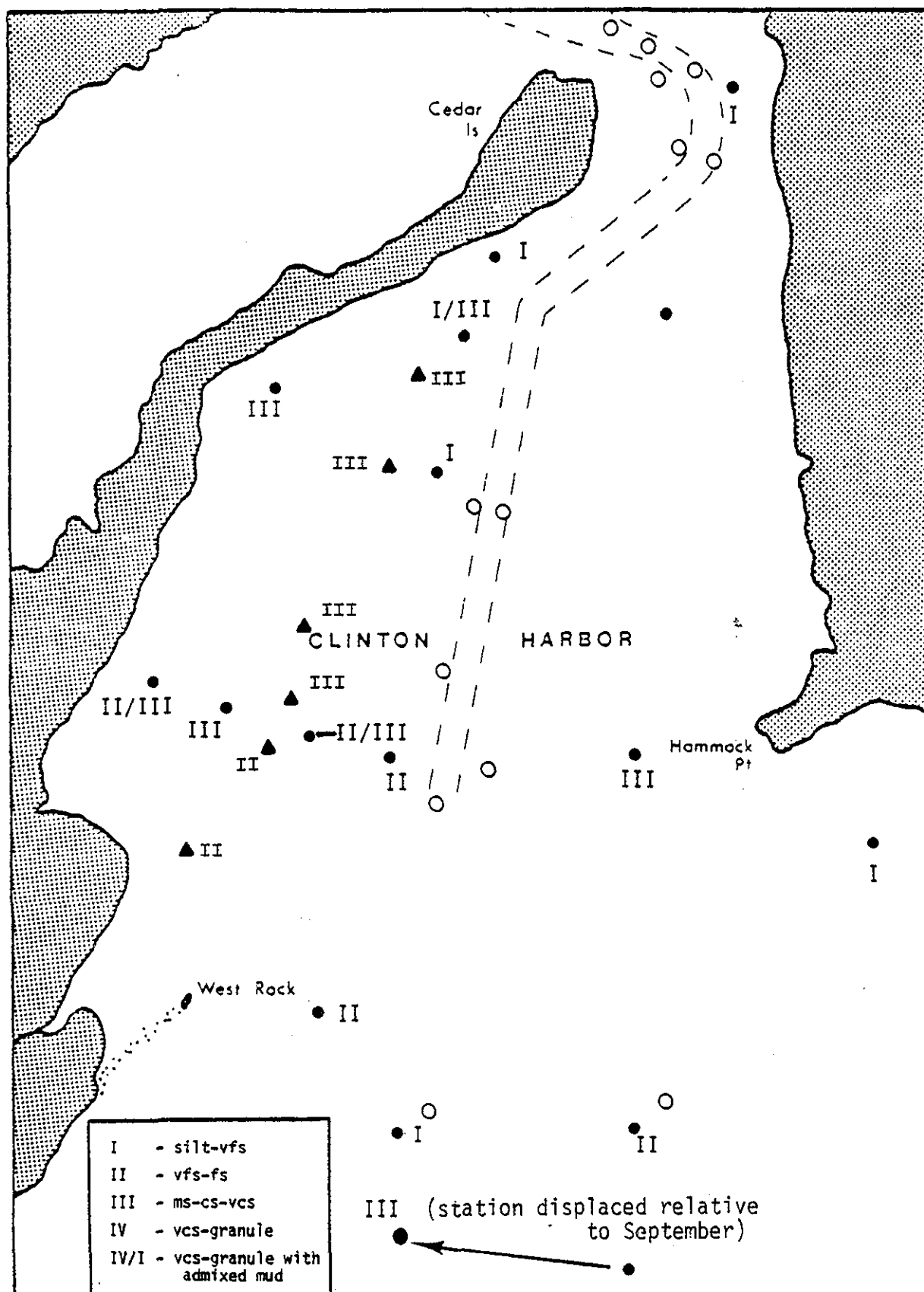
Figure 2B. Station values for grain size groupings for October 1981.

Cedar Is

I

I/III

III

III

III

I

III

C L I N T O N   H A R B O R

III

II/III

III

III

II/III

II

II

II

Hammock Pt

III

I

West Rock

II

I   - silt-vfs
II   - vfs-fs
III   - ms-cs-vcs
IV   - vcs-granule
IV/I - vcs-granule with
        admixed mud

I

II

III   (station displaced relative
       to September)

4

Planimetered RPD Area	Index Value
0-10 cm^2	1
10.1 = 20.0	2
20.1 = 30.0	3
30.1 = 40.0	4
40.1 = 50.0	5
50.1	6

Successional Stage	Index Value
Azoic	-5
Stage 1	1
Stage 1-2	2
Stage 2	3
Stage 2-3	4

Chemical Parameters	Index Value
Methane present	-2
No/low dissolved O_2	-4

The indices are assigned such that the highest possible ranking is +10, i.e., a Stage 2-3 successional sere with a deep redox (> 50.1 cm^2) and no methane present. The lowest ranking is -10, i.e., an azoic bottom containing methane and no dissolved oxygen (RPD index value is +1). For further explanations, see CEM Report No. 4280-02-738 (December 1981). Appendix D presents summary tables of the sediment profile photography data.

Results

The distribution of sedimentary facies in Clinton Harbor for September and October exhibits some temporal variation (see Figures 2A and 2B). Fine grained stations (Group IV) are represented by stations 2 and 14 (Zostera bed) and a local mud patch surrounded by a coarse grained substratum (Station 4).

Seven September stations in the outer and eastern regions of the harbor cluster into a vfs-fs (Group II) region (Stations 3,5,6,7,10,11 and 12). Station 13, which is near shore off Cedar Island, also consists of vfs-fs. In October, changes in sediment textural groups have taken place, and Stations 3,5,6,7,12 and TO-1 and TO-2 cluster into a Group II sediment type.

Medium sands to granule-sized sediment occupy most of the area of the open harbor on the west side of the navigational channel (Group III). The coarsest sediments (IV) occur to the south and west of Hammock Point. However, these coarse sediments (IV) are mixed with muds, and some muds apparently accumulate in local patches (e.g., Station 4). These areas are therefore designated as Group IV/I.

In September 1981, all stations located on sediment Groups I and II in water depth > 3 meters were in Stage I succession (Figure 3) . Habitat indices were obtainable for Stations 1 (+5), 2 (+5), and 6 (+3). All stations were aerobic and no methane was observed.

A well-developed eel grass bed is located at Station 14 and poorly developed grass patches were observed on the photo transect. Bottom areas near Station 8 were occupied by a dense aggregation of Crepidula fornicata.

The October 1981 faunal and habitat data is comparable to that of September (Figure 4). By these data, the Zostera bed at Station 14 was defoliating with concommitant erosion of the fine-grained sediments trapped between the grass roots. The Group II and III sands to the west of the approach channel showed evidence of head-down deposit-feeders (sand cones at the sediment surface). These may represent populations of maldanid polychaetes. These fecal cone structures were present in both September and October.

BOTTOM STABILITY

Methods

The sediment-profile camera can provide useful data for estimating critical bottom shear stress (τ_0) and mean critical bottom shear velocity ($\bar{u}_*$) approximations in sandy (noncohesive) areas where no ground-truth grain size data are available and current-meter data are lacking. The photographs are inspected with a visual grain-size comparator, as described earlier, and the range of grain-sizes is estimated along with the major modal size.

The major modal size (in cm) is then "plugged" into a modified Shields curve (Shields, 1936; Madsen and Grant, 1976), where the boundary Reynolds number (R_*) is replaced with a parameter S_*, which is a function of sediment and fluid properties only:

$$S_* = \frac{d}{4\nu} \sqrt{(S-1)\ gd}$$

(1)

6

Figure 3. Successional stage station values for September.
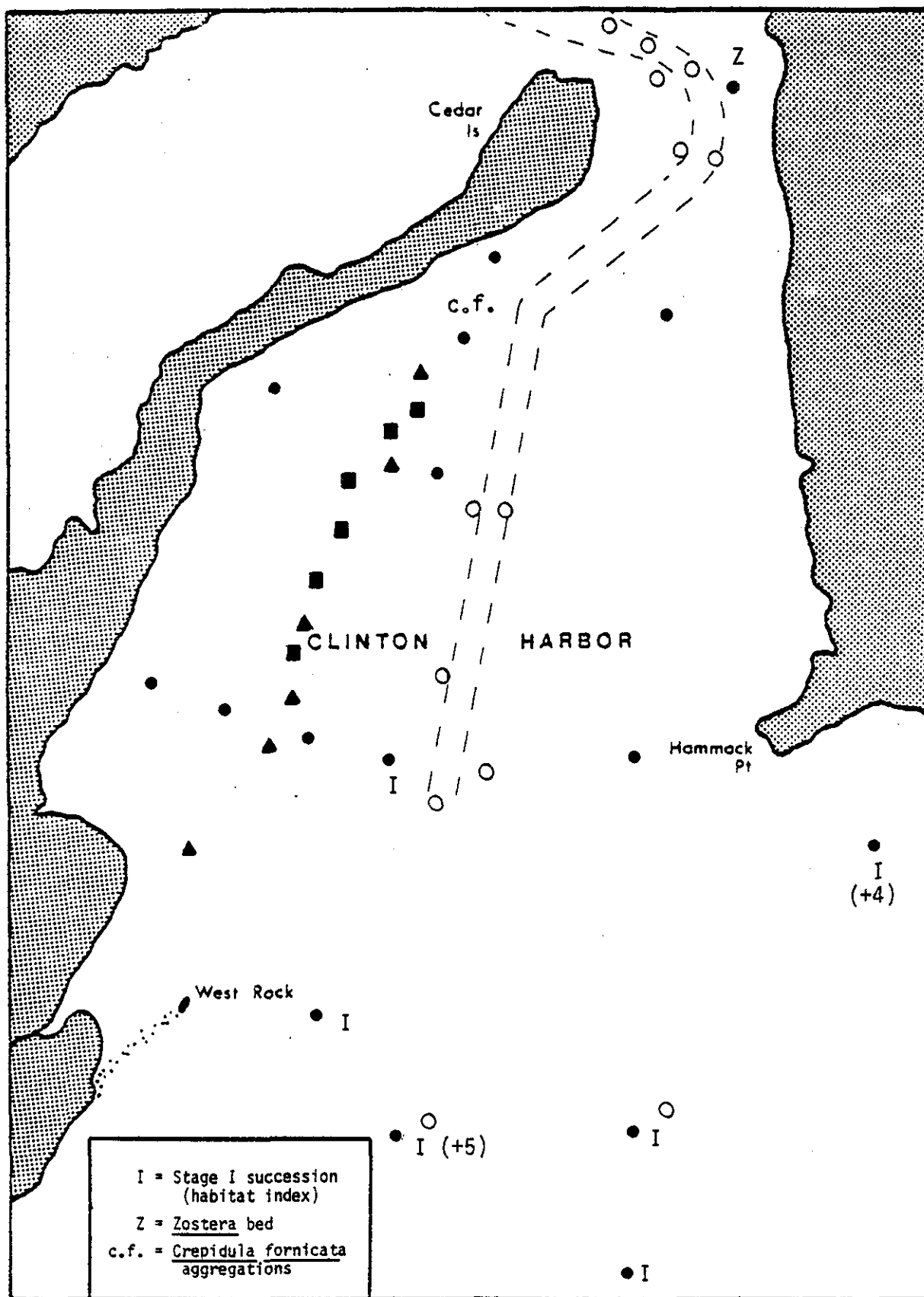
Figure 4. Successional stage station values for October.

where

 d = . grain meter (in cm)

 ν = kinetic viscosity ($\sim 10^{-2}$ poise)

 S = relative density of the particle (i.e., quartz = 2.65)

 g = acceleration due to gravity (980 cm/s^2)

Knowing the sediment and fluid properties above, one can calculate S_* and from Figure 5, the critical value of dimensionless shear ψ, the Shields parameter, can be estimated. Where:

$$\psi = \frac{\tau_o}{(S-1)\ \rho g d} \tag{2}$$

and

 τ_o = bottom shear stress (in dynes/cm^2)

 S = relative particle density (2.65 for quartz)

 p = density of salt water (~ 1.04), fresh = 1.0 g/cc

 g = 980 cm/s^2

 d = grain diameter (in cm)

Solving for τ_o one can then estimate the minimum bottom shear stress, and the minimum critical shear velocity (u_*) for initiating sediment motion, assuming a fully developed flow over a flat bottom.* J. C. Harms (1969) illustrates (Figure 6) how the values of the Shields parameter ($\theta=\psi$) might vary from the flat plate condition to low and high energy ripple conditions. At our stations where ripples are present (see Figures 7 and 8), a large range of τ_o and u_* is indicated. The combined wave and current problem (Grant and Madsen, 1982) is much too complex for the limited data available. Therefore, we will use the flat plate comparison as a conservative estimate of the mean bottom shear stresses and critical shear velocities present.

To estimate potential depth-averaged velocities $\bar{u}$ in the field environment, a Reynolds number can be estimated for the flow regime. Moreover, assuming that in a tidal current we have fully developed turbulent flow, where $u_* k_s / \nu \gtrsim 70$ (i.e., boundary effects are transitional), we can estimate $\bar{u}$ in a logarithmic velocity distribution where:

$$\frac{u}{\bar{u}} = \left(\frac{1}{\kappa}\ \ell n\ \frac{y}{k_s} + B_s\right) \tag{3}$$

---

*

 As $u_*^2 = \sqrt{\tau_o / \rho}$

9

Figure 5. Modified shields diagram for the initiation of sediment movement.
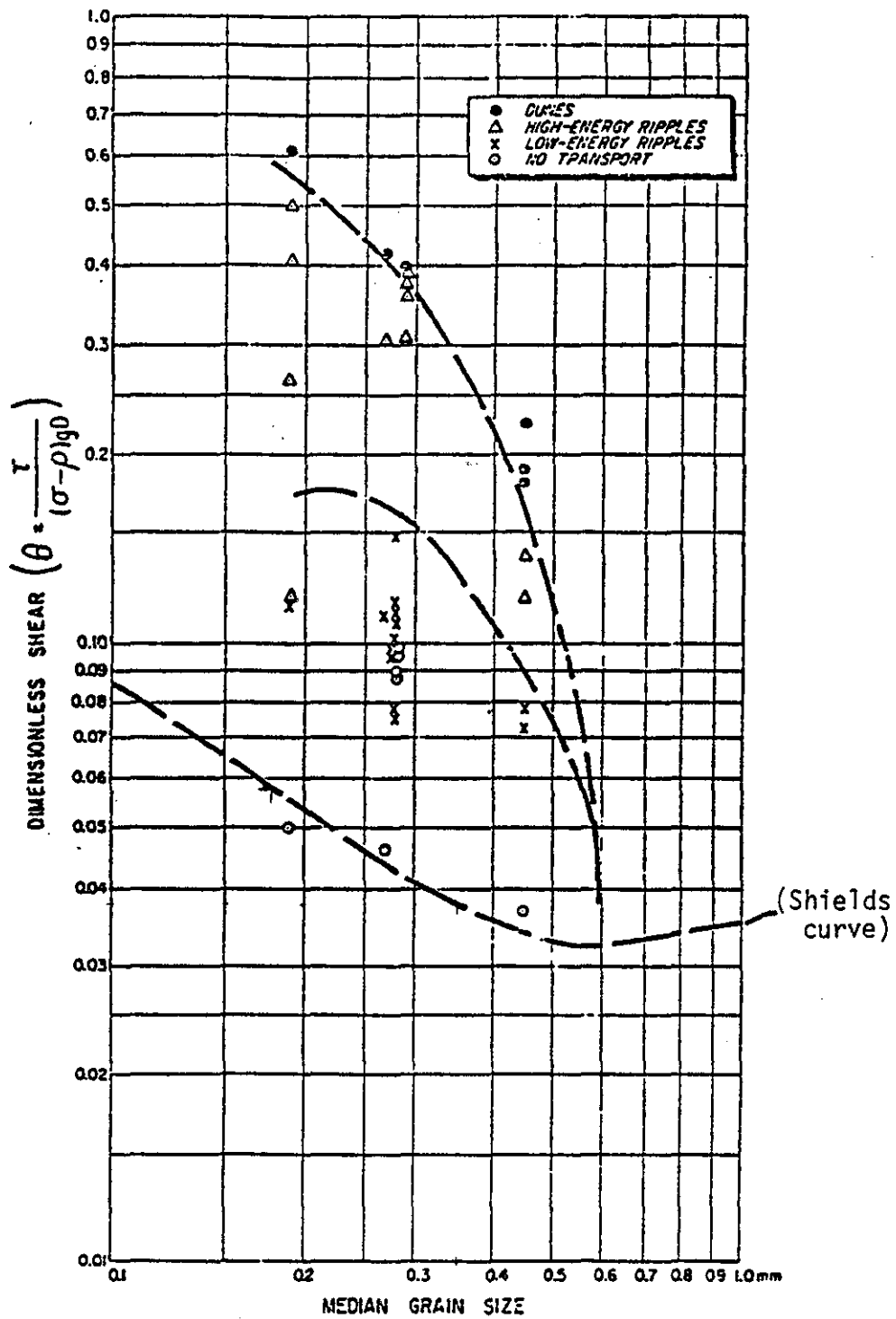
Figure 6.   Dimensionless shear for current ripples composted of sands with differing median grain sizes.

I	min U_* (cm s^{-1})		1.21–1.32
	min r (dynes cm^{-2})		1.46–1.74
II	min U_* (cm s^{-1})		1.21
	min r (dynes cm^{-2})		1.46
III	min U_* (cm s^{-1})		1.61–2.31
	min r (dynes cm^{-2})		2.59–5.34
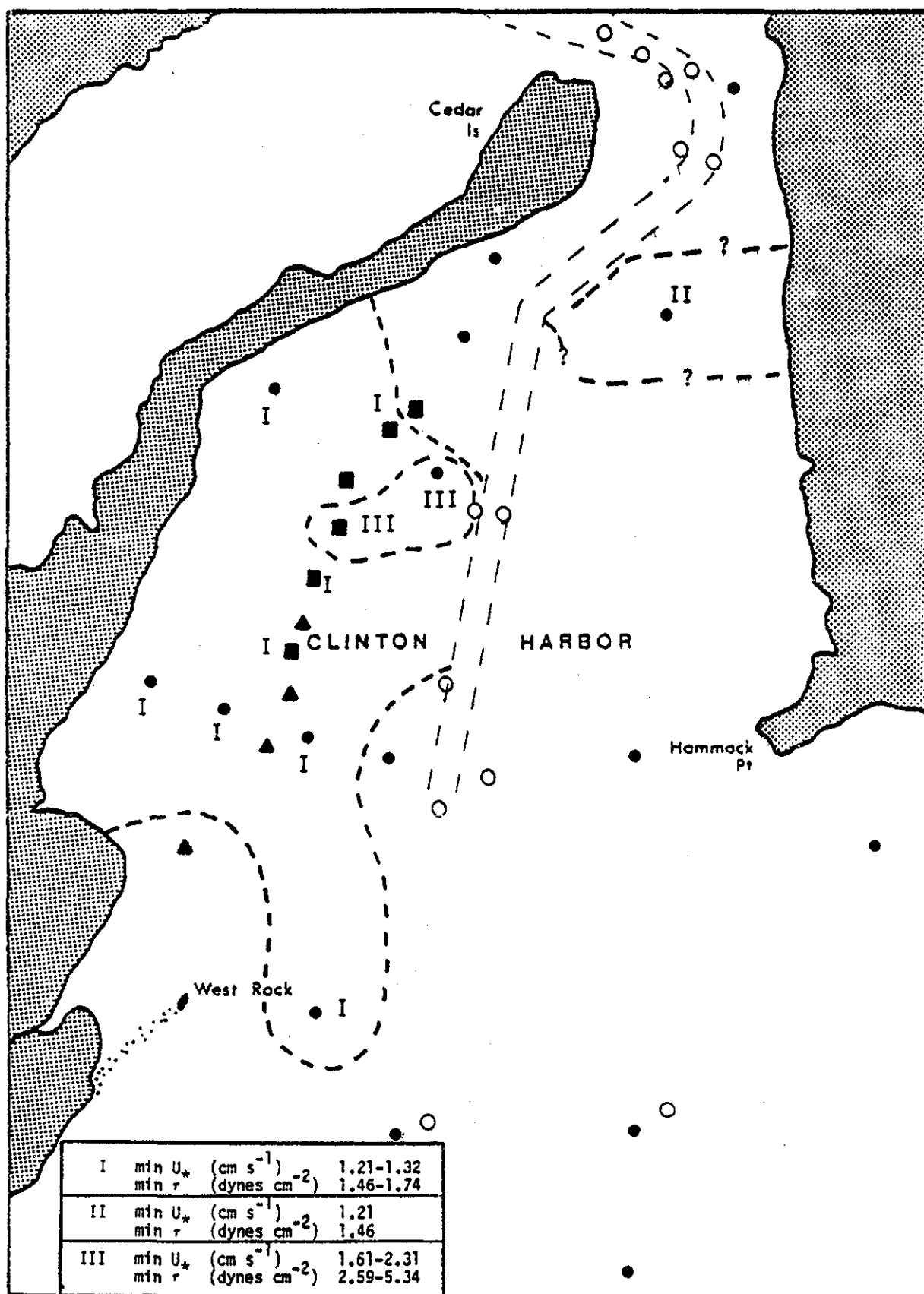
Figure 7.   Station area values for unstable bottom values for September.

I	min U_* (cm s^{-1})		1.21–1.32
	min r (dynes cm^{-2})		1.46–1.74
II	min U_* (cm s^{-1})		1.21
	min r (dynes cm^{-2})		1.46
III	min U_* (cm s^{-1})		1.61
	min r (dynes cm^{-2})		2.59
IV	min U_* (cm s^{-1})		1.32
	min r (dynes cm^{-2})		1.74
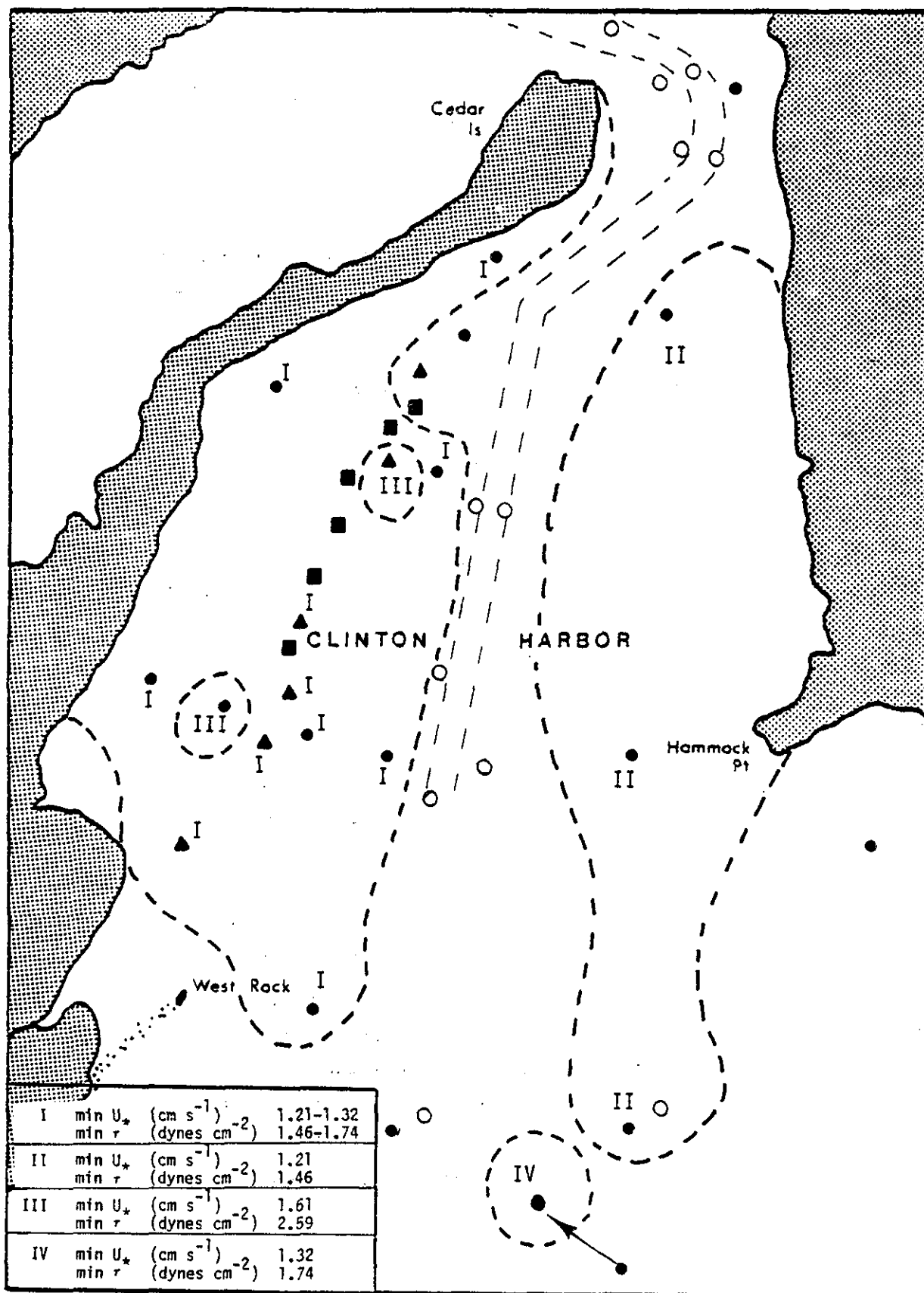
Figure 8. Station area values for unstable bottom values for October.

where

κ = 0.4 (von Karman constant)

k_s = grain diameter (in cm)

y = depth of water (in cm)

B_s = 8.5 (constant)

(see Yalin, 1977). For example, for a water depth of 2 meters, typical of Clinton Harbor outside of the channel, grain diameter of 250μ (ms) and corresponding u_* of 1.32 cm/s (calculated from Figure 5):

$$\bar{u} = (\frac{1}{0.4} \ln \frac{182.9}{.025} + 8.5)1.32$$

$$(2.5 \times 8.9 + 8.5)1.32$$

$$\bar{u} = 40.6 \text{ cm/s}$$

Results

Figures 7 and 8 illustrate the areas of Clinton Harbor dominated by the presence of rippled bottom. In most cases, these ripples are asymmetric, suggesting they are generated by unidirectional tidal flow. However, some have complex geometries, presumably related to the interaction of tidal flow with the obitals of wind waves (see Madsen and Grant, 1976; Grant and Madsen, 1982).

The area of unstable bottom (i.e., ripple fields) appears to increase in October relative to September. The area of the harbor west of the channel, in the region between Hammonasset Point and Cedar Island, as well as the area near Station 12 on the east side of the channel, are particularly unstable.

Those rippled bottom areas located in regions of sediment Group II and III (Figures 2A and 2B) have a range of predicted (Equation 3) minimum $\bar{u}$'s (2 meters of water) from $\bar{u} \simeq 36$ cm/s (vfs) to $\bar{u} \simeq 63$ cm/s (vcs). These estimations are based on a flat plate model with fully developed flow conditions and the absence of biological binding of the sediments. Velocities and bottom shear values in the field may be much greater (see Figure 6), especially where ripples are present (Harms, 1969; Grant, et al., 1982; Grant and Madsen, 1982). Moreover, Bohlen (1982) concludes that resuspension events in Long Island Sound are the result of these combined wave and tidal currents, and waters less than 20 m depth in this region may commonly experience major resuspension events three to five times per year.

DISCUSSION

The information gained from the sediment profile photographs show that the area of Clinton Harbor to be used for a DMCF consists mainly of medium to fine sands that is subjected to strong tidal flow. It is important to bear in mind that the additional effects of waves due to seasonal storms will augment the sediment transport capacity of this mean tidal flow. This area of bottom is particularly unstable, as is evidenced by the presence of rippled bed forms. However, another consequence of the high input of physical energy to this area is that the habitat value from a biological standpoint is relatively low. Biological data from the sediment profile photographs show that the stations in the DMCF site where habitat indices could be calculated (i.e., where there was adequate camera presentation) contain a Stage I successional assemblage, lending support to the conclusion that this is an area in a frequently disturbed physical regime. Such low order successional stages can prove to be highly productive unless the frequency of disturbance is too high (Rhoads, et al., 1978).

When the data obtained from the benthic grab samples are incorporated, the DMCF site is seen to be dominated by Streblospio benedicti and Tellina agilis in moderate to low densities. Secondary production estimates for these species in the highest densities found in this area are given in Table 1. The estimated annual production of approximately 10.5 gm^{-2} is relatively low compared with other Stage I successional assemblages in Long Island Sound. For example, the production at station FOAM (14 meters depth) near the Thimble Islands is conservatively estimated to be ca. $77 \text{ g m}^{-2} \text{ yr}^{-1}$. This production is contributed by Streblospio benedicti, Capitella capitata, and Ampelisca abdita (Rhoads, et al., 1978). With the low densities observed in the Clinton Harbor area, it is felt that the impact on fish stocks using this area as a food source would also be negligible.

The creation of additional marsh area as proposed could potentially increase the biological habitat value of the harbor. Estimates of secondary production from a typical New England salt marsh are given in Table 2. The additional marsh area would also provide more spawning areas for fish populations as well as increase the amount of spatial resources for salt marsh invertebrates, juvenile fish, and birds. The proposed containment of the DMCF by rip-rap construction would also provide a large amount of surface area for the development of hard-substratum communities. This would increase secondary marine production, providing a greater potential food supply for commercial fish stocks in the Clinton Harbor area as well as a suitable habitat for

15

TABLE 1

SECONDARY PRODUCTION ESTIMATES, CLINTON HARBOR DMCF SITE

Species (Dominants)	Peak Densities (m^{-2})	Individual Biomass	Biomass m^{-2} (mg)	P/B[*]	Annual Production (gm^{-2})
Streblospio benedicti	2250	ca.0.1 mg	225	~ 5	1.1
Tellini agilis	625	ca. 5 mg[*]	3125	~ 3	9.4 Σ = 10.5

[*]From Rhodes, McCall and Yingst, 1978, Disturbance and production on the estuarine seafloor. Am Sci. 66: 577-586.

TABLE 2

SPARTINA MARSH SECONDARY PRODUCTION

Species	$\bar{x}$ m^2	X Age (Year)	Individual Biomass (mg) ②	P/B ③	Estimated Annual (Growth) Production
Geukensia demissa ① (adult population)	Marsh edge - 700 Marsh flat - 234 Short Spatina zone - 30	5.6 5.7 8.0	ca.500 ca.500 ca.500	0.1 0.1 0.1	35 gm 12 gm 1.5 gm
G. demissa (juvenile population)	Marsh edge - 100	2.0	ca. 25	1.1	2.8 gm
G. demissa ② (adult population)	~ 6	"Mature"	ca.500	0.15	0.45
TIDAL CREEK SECONDARY PRODUCTION ④					
Streblospio benedicti (only)	3916		0.1 5	6 ⑤	2.3
Total Species (based on May-June data)				3 ⑥	5.4
COMPARISON OF SECONDARY PRODUCTION					

Existing production (Table 1)   ~ 11 gm/m^2/yr

Marsh mussel (ribbed) (above)   3 - 35 gm/m^2/yr

Tidal Creek production (above)   6 gm/m^2/yr

① From data on Smith Cove, Barrington, Rhode Island, NSF proposal by Mark D. Bertness, University of Rhode Island.

② From data on Sapelo Island, Georgia, Kuenzler, E.J., 1961, Structure and energy flow of a mussel population in a Georgia salt marsh: L & O, 6, 191-204.

③ Estimated from Warwick, R.M., 1980, Population dynamics and secondary production of benthos, In, Marine Benthic Dynamics (Tenore & Coull, eds.), Belle Baruch Symposium #11, Univ.of South Carolina Press, pp. 1-24.

④ Data from Great Sippewissett Marsh, Falmouth, Cape Cod from Wiltse, W.I., K.H. Formena, J.M. Teal and I. Valiela, in press, Role of predators and food resources in regulating the macrobenthos of salt marsh creeks: Jour.Mar. Res.

⑤ From Rhoads, D.C., P.L. McCall and J.Y. Yingst, 1975, Disturbance and production on the estuarine seafloor: Am. Sci., 66, 577-586.

⑥ Based on a mean P/B for cohorts one year old. From Warwick, R.M., 1980.

16

commercially important invertebrate species (e.g., crabs, lobsters, mussels). The construction of the DMCF as proposed can only enhance the biological value of the area. The greatest potential for enhanced secondary production would be related to colonization of the rip-rap by the blue mussel Mytilus edulis. Production potential for this species is very high and could reach values greater than 200 g m^{-2} yr^{-1} (Barnes and Green, 1971).

However, construction of the DMCF may significantly alter current patterns and energy input to Clinton Harbor, and further studies are necessary to evaluate the full impact of the DMCF on the remaining harbor ecosystem. The high amount of energy being delivered to the proposed DMCF site in the form of tidal flow and wave energy will obviously be diverted to another region in the harbor. Without further studies, it would be impossible to predict accurately which areas in the harbor would be altered; for example, the mud areas to the east of the current channel could be scoured out and the material deposited during flood tides where the Cedar Island marina exists (see Figure 4-10, CEM report). Enhanced deposition of coarse-grained material in the outer channel as a result of long-shore drift is also possible, as are any number of other undesirable effects.

In view of possible changes in the total water energy regime—due to wind waves as well as tidal currents—wave refraction studies should be conducted. The wind wave refraction study could be supplemented by concurrent sediment transport studies in the area of Hammonasset Point. The southwestern corner of the proposed dike wall would experience the same input of wave energy as Hammonasset Point; this would allow accurate predictions to be made about how the construction of the DMCF will affect the sediment budget of the area, particularly inside Clinton Harbor.

The resulting change in current flow and other physical aspects of the environment could in turn affect the distribution of the benthos. We can make some gross predictions about the fate of the existing successional seres after emplacement of the DMCF. The facility could alter the biological structure of the harbor by shifting the area of severe physical disturbance offshore, as wave and tidal energy will be concentrated on the outer side of the rip-rap breakwater. These opportunistic assemblages would probably cover a greater area than present after emplacement of the DMCF, because the sands in front of Cedar Island are extremely poor dissipators of wave energy.

17

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SECTION IV

BIOTIC SURVEY

OF CLINTON HARBOR, CT

Taxon, Inc.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES
(Continued)

1.0 INTRODUCTION

This study was performed as part of a multidisciplinary investigation of the environmental characteristics of Clinton (Connecticut) Harbor in connection with the potential creation of a dredged material containment facility (DCMF). This section of the final report includes studies undertaken by Taxon, Inc., in the following areas: benthic macrofauna, finfish, shellfish, algae, marsh plants, and sediments. Additional investigations were conducted by subcontractors and include: sediment-water inter- face photography and habitat evaluation (Marine Surveys, Inc.), hydrodynamics (The Center for the Environment and Man, Inc., and Ocean Surveys, Inc.), and marsh creation feasibility (Environmental Concern, Inc.).

In any project, such as the proposed DCMF at Clinton, involving removal or deposition of bottom sediments over a large area, the benthic infauna are the most directly impacted faunal group. Benthic organisms are non-motile with respect to the spatial scope of most such projects, and are unable to avoid their effects. In addition, most benthic species are closely dependent upon the nature of the bottom substratum and can survive only within a discrete range of bottom types. Because such projects usually involve changes in bottom sediments, they are capable of producing widespread alterations in benthic community types.

The proposed project at Clinton would result in the elimination of the benthic macrofaunal community from most of the disposal area and the establishment in its place of various types of "marsh" habitats. The elimination of the macrobenthos may be considered a negative impact and the creation of the marsh a positive impact. The relative valuation of these two community types was addressed in Section II of this report and the net impact to the Clinton Harbor area was determined to be positive based upon increased habitat diversification and enhanced productivity. The present condition of the area, which was used to develop that conclusion, is described in this section of the report.

The benthic macrofaunal phase of this investigation was conducted to determine the nature and extent of benthic macrofaunal communities in the proposed disposal area and to evaluate the importance of the area for the Clinton Harbor ecosystem. Most intensive sampling, therefore, was conducted within the proposed boundaries of the disposal area. In order, however, to address the importance of the area as habitat it was necessary to collect samples from other areas of the harbor. Additional stations were established throughout the outer harbor area and beyond the harbor boundaries. The placement of these stations was designed to allow determination of the extent of bottom substratum types and benthic communities similar to those

1

within the disposal area and to provide comparative data to evaluate the relative importance of the area which would be eliminated from the harbor system should the disposal project be undertaken.

In addition to the elimination of the invertebrate infauna from most of the area within the proposed DCMF, algal populations in the intertidal zone, and any shellfish resources in the filled area would also be eliminated. These two groups were the subject of two special investigations conducted simultaneously with the infauna sampling. In order to fully document conditions in the subject area, an inventory was made of the plants species currently found in Hammonasset Marsh.

Finally, a series of finfish collections was made to document the finfish populations residing in the harbor. This included analysis of gut contents to allow the evaluation of the effect of a reduction in quantity of available benthic invertebrates on the various icthyofauna.

2.0   BENTHIC MACROFAUNA

2.1   Methods

Benthic macrofaunal sampling was conducted at Clinton Harbor on 2-3 September 1981, and 26-27 October 1981. In order to ensure comparability of station locations, macrofaunal collections were made concurrently with the interface photography. Station locations were determined by bearings on fixed landmarks using a hand-bearing compass, ranges on landmarks, distance measurements using an optical ranging device, and fathometer. A complete summary of the various procedures used to locate each station is provided by station in Appendix B. All sampling was conducted from a 35' boat with approximately 2' draft.

A $0.04m^2$ modified Van Veen grab sampler was used to collect two replicate samples at each of sixteen stations during both of the sampling periods. Station locations are shown in Figure 1. Approximately 50g of sediment was removed from the surface of each sample for sediment grain-size analysis. The remainder of the sample was sieved in the field through a 0.5mm mesh stainless-steel sieve and fixed in 10% buffered seawater formalin. After 48 hours, samples were washed and preserved in 70% isopropanol. Prior to sorting, samples were stained with Rose Bengal to facilitate separation of the smaller macrofauna from residual sediment and detritus.

Sample processing was accomplished via a two-stage sorting procedure. Initial separation of macrofauna from residue and classification into large taxonomic groups was performed by technicians using stereomicroscopes. Final identifications were determined by experienced taxonomists using stereomicroscopes and compound microscopes, as necessary. Data were recorded on hand-written sheets and entered directly into the Woods Hole Oceanographic Institution (WHOI) Sigma 7 computer from a remote terminal located at Taxon, Inc. Appendix C summarizes raw infaunal data.

Data processing and analysis were performed using a number of programs developed at WHOI expressly for benthic data sets. The program PRARE1 was used for data summary and calculation of a number of diversity indices. The programs PERSORT and SPSORT were used to reduce the data set, via elimination of rare species, prior to classification analysis, which was subsequently performed via the Bray-Curtis similarity measure and UPGMA sorting using the program SPSTCL.
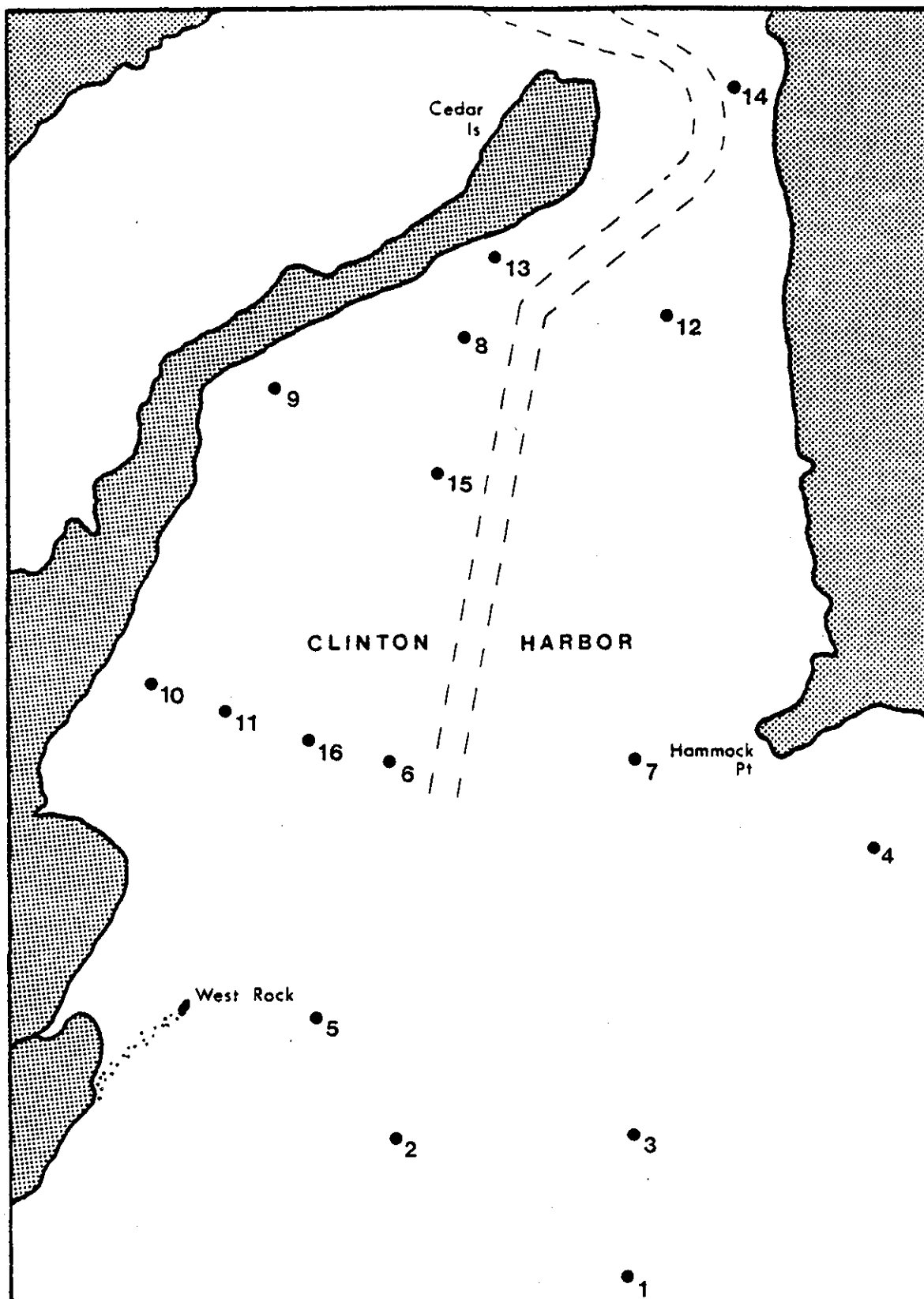
Figure 1. Study area and sampling station locations.

2.2 Results

2.2.1 Species Composition

A complete list of all taxa collected during the study is presented in Table 1. Within each large taxonomic group, species are arranged in approximate order based upon their frequency of occurrence over both samplings. The list includes 145 taxa with the dominant taxonomic group being the polychaetes (54 taxa), followed by the amphipods (22 taxa), gastropods (19 taxa) and bivalves (17 taxa).

For the September sampling, the most widespread species of the 96 taxa collected in the study area was the polychaete Streblospio benedicti which was present at every station and was collected in 30 (94%) of the 32 samples. The bivalve Tellina agilis was nearly as ubiquitous, occurring in 28 (88%) of the samples and being present at 15 of the 16 stations. The remaining common species were not so widespread, occurring in less than 75% of the samples, and included the polychaetes Glycera americana, Tharyx acutus, Mediomastus ambiseta and Paraonis fulgens and the Oligochaetes. The 33 most common species, those occurring in more than 10% of the samples, are ranked in Table 2.

The October sampling included 111 species, a 16% increase over September. The two dominant species were again Tellina and Streblospio with Tellina occurring in every sample and Streblospio occurring in 30 samples and being present at every station. Although Tellina was slightly more widespread, Streblospio was generally much more numerous. With the exception of Paraonis fulgens, all of the common species noted above for the September sampling were again common in October. In addition, the polychaetes Nephtys picta and Spiophanes bombyx were very widespread in the study area in October. The 35 most common species, those occurring in more than 20% of the samples, are ranked in Table 3. All raw data from the benthic infaunal sampling are included in Appendix 2.

The pattern of species composition between the two sampling events is very similar and is indicative of a degree of stability in the faunal communities occupying the outer Clinton Harbor area. The ranking of the 30 most common species, as determined by combining the data from both samplings, were tested via Spearman's Coefficient of rank correlation and found to be significantly correlated at $p < .01$ (r_s = .54; df = 29).

The species list from the present study is considerably larger than the 68 species collected in a similar survey in Clinton Harbor conducted in the fall of 1977 (McGrath, et al., 1978). That survey was not as extensive as the present study, but did include

TABLE 1

TAXONOMIC LISTING OF MACROBENTHIC INVERTEBRATES FROM
CLINTON HARBOR (CT), SEPTEMBER 1981 AND OCTOBER 1981

Bivalves

Tellina agilis
Mulinia lateralis
Gemma gemma
Nucula proxima
Ensis directus
Lyonsia hyalina
Yoldia limatula
Pandora gouldiana
Spisula solidissima
Bivalvia unident.
Aequipecten irradians
Anadara transversa
Nucula delphinodonta
Thracia septentrionalis(?)
Tellina sp.
Mya arenaria
Mytilus edulis

Gastropods

Nassarius trivittatus
• Crepidula fornicata
Ilyanassa obsoleta
Crepidula plana
Turbonilla sp.
Acteocina canaliculata
Edotea triloba
Mitrella lunata
Gastropoda unident.
Cylichna oryza
Crepidula convexa
Lacuna vincta
Odostomia bisuturalis
Crepidula sp. (juv.)
Bittium alternatum
Alvania areolata
Corambella sp.
Odostomia sp.
Turbonilla elegantula

Amphipods

Unciola irrorata
Listriella barnardi
Ampelisca abdita
Trichophoxus epistomus
Paraphoxus spinosus
Melita nitida
Caprellidae
Protohaustorius deichmannae
Photis reinhardi
Ericthonius brasiliensis
Caprella penantis
Ampelisca agassizi
Acanthohaustorius millsi
Elasmopus levis
Aeginina longicornis
Unciola sp.
Unciola serrata
Monoculodes sp.
Jassa falcata
Amphipoda unident.
Amphithoe valida
Corophium bonelli

Crustacea

Pagurus longicarpus
Oxyurostylis smithi
Cytheridea americana
Cirripedia
Neopanope sayi
Ovalipes ocellatus
Crangon septemspinosa
Heteromysis formosa
Idotea balthica
Leptochelia savignyi
Upogebia affinis
Cylindroleberis mariae
Hutchinsonella macracantha
Balanus improvisus
Idotea phosphorea
Sarsiella sp.
Pinnixa sp.
Cancer irrorutus
Leucon americanus
Chiridotea tuftsi
Neomysis americana
Palaemonetes vulgaris
Hippolyte zostericola

TABLE 1 (Continued)

Annelida

Streblospio benedicti
Tharyx acutus
Glycera americana
Mediomastus ambiseta
Oligochaeta
Spiophanes bombyx
Nephtys picta
Scoloplos acutus
Syllinae/Eusyllinae
Paraonis fulgens
Aricidea sp.
Polygordius spp.
Anaitides spp.
Pectinaria gouldii
Exogone sp.
Asabellides oculata
Nephtys incisa
Scolecolepides viridis
Eumida sanguinea
Polydora socialis
Clymenella torquata
Capitella capitata
Eteone heteropoda
Lumbrineris sp.
Magelona rosea
Nereis sp.
Sabellaria vulgaris
Harmothoe imbricata
Lepidonotus squamatus
Polydora ligni
Hydroides dianthus
Maldanidae unident.
Dorvilleidae unident.
Cossura longocirrata
Anaitides arenae
Scoloplos squamata
Phyllodocidae unident.
Polychaeta unident.
Schistomeringos caecus
Nereis zonata
Scoloplos robustus
Paranaitis speciosa
Spiochaetopterus oculatus
Spio filicornis
Nereis grayi
Polycirrus sp.
Pista palmata
Eulalia viridis
Drilonereis longa

(Annelida cont.)

Nereis arenaceodonta
Sigambra tentaculata
Owenia fusiformis
Glycera sp.
Polydora sp.
Glycera dibranchiata
Polydora commensalis

Misc.

Tubulanus pellucidus
Nemertea unident.
Turbellaria
Phoronida
Euplana gracilis
Holothuroidea
Ophiuroidea

TABLE 2

33 MOST COMMON SPECIES (OCCURRING IN GREATER THAN 10% OF ALL SAMPLES) - SEPTEMBER 1981

Species/Taxa	No. Samples	Percent
Streblospio benedicti	30	93.8
Tellina agilis	28	87.5
Glycera americana	24	75.0
Tharyx acutus	23	71.9
Mediomastus ambiseta	23	71.9
Oligochaeta	20	62.5
Paraonis fulgens	16	50.0
Mulinia lateralis	14	43.8
Scoloplos acutus	14	43.8
Spiophanes bombyx	13	40.6
Gemma gemma	12	37.5
Aricidea sp.	10	31.2
Syllinae/Eusyllinae	10	31.2
Clymenella torquata	8	25.0
Ampelisca abdita	8	25.0
Nephtys incisa	8	25.0
Pagurus longicarpus	7	21.9
Polygordius spp.	7	21.9
Listriella barnardi	6	18.8
Nemertea	6	18.8
Ensis directus	5	15.6
Exogone sp.	5	15.6
Nassarius trivittatus	5	15.6
Scolecolepides viridis	5	15.6
Eumida sanguinea	5	15.6
Tubulanus pellucidus	5	15.6
Nucula proxima	4	12.5
Corophium bonelli	4	12.5
Ilyanassa obsoleta	4	12.5
Lumbrineris sp.	4	12.5
Pectinaria gouldii	4	12.5
Oxyurostylis smithi	4	12.5
Capitella capitata	4	12.5

TABLE 3

34 MOST COMMON SPECIES (OCCURRING IN GREATER THAN 20% OF ALL SAMPLES) - OCTOBER 1981

Species/Taxa	No. Samples	Percent
Tellina agilis	32	100.0
Streblospio benedicti	30	93.8
Nephtys picta	29	90.6
Tharyx acutus	28	87.5
Glycera americana	27	84.4
Mediomastus ambiseta	26	81.2
Spiophanes bombyx	23	71.9
Oligochaeta	20	62.5
Syllinae/Eusyllinae	20	62.5
Mulinia lateralis	19	59.4
Tubulanus pellucidus	16	50.0
Scoloplos acutus	16	50.0
Anaitides sp.	14	43.8
Pagurus longicarpus	14	43.8
Gemma gemma	12	37.5
Cytheridea americana	12	37.5
Aricidea sp.	12	37.5
Nassarius trivittatus	12	37.5
Unciola irrorata	12	37.5
Pectinaria gouldii	11	34.4
Asabellides oculata	11	34.4
Oxyurostylis smithi	11	34.4
Crepidula fornicata	11	34.4
Cirripedia	11	34.4
Paraonis fulgens	10	31.2
Ilyanassa obsoleta	9	28.1
Exogone sp.	9	28.1
Polygordius spp.	9	28.1
Nemertea	8	25.0
Turbonilla sp.	7	21.9
Eteone heteropoda	7	21.9
Acteocina canaliculata	7	21.9
Crepidula plana	7	21.9
Polydora socialis	7	21.9
Scolecolepides viridis	7	21.9

stations in the inner harbor which represents a habitat type not sampled during the 1981 program. On that basis, the present species list does appear to indicate that the resident fauna were more diverse in 1981 than in 1977.

A survey of the Clinton Harbor system in 1975 (Pellegrino and Baker, 1975) collected only 30 species but those data are not strictly comparable to the present study due to differences in methods and personnel, both of which can alter the number of species reported.

2.2.2 Species Richness

Species richness, calculated as mean number of species per $0.04m^2$ grab, is presented in Figure 2 for the September sampling and Figure 3 for October.

In September, richness varied from a low of 7 species/$0.04m^2$ at Station 2 to a maximum of 32.5 species/$0.04m^2$ at Station 14. More typical values ranges from 10-15 species, a range which included most of the stations located within the proposed container disposal area. The abnormally high value recorded from Station 14 reflects the fact that this was the only area sampled which supported an eel-grass bed, commonly known to be an extremely productive estuarine community type. High species richness was also recorded at Station 8, which was the only station sampled which had a shell and gravel substratum characterized by a dense Crepidula fornicata population.

In October, species richness at all stations was greater than in September. Station 2 was again the lowest with 14 species/$0.04m^2$ and Station 14 again had the highest richness at 38.5 species. The general range of richness at most stations was increased by over ten species and was about 20-30 species/$0.04m^2$. As before, this range included most of the stations within the proposed disposal area.

2.2.3 Faunal Density

Faunal densities, calculated as mean number of individuals/m^2 are presented in Figure 4 for the September sampling and Figure 5 for October. These numbers should not be combined directly with those presented earlier for species richness because the species richness values were not normalized to square meter area.

The pattern of faunal densities is somewhat more complicated than that described above for species richness. In September, highest densities were found at Station 14, with 19,462 individuals/m^2 while Station 15 was least dense with only 1,050 individuals/m^2. Most stations had densities in the range of 3,000 to 10,000 individuals/m^2 with most stations in the disposal area having densities toward the lower end of this range.
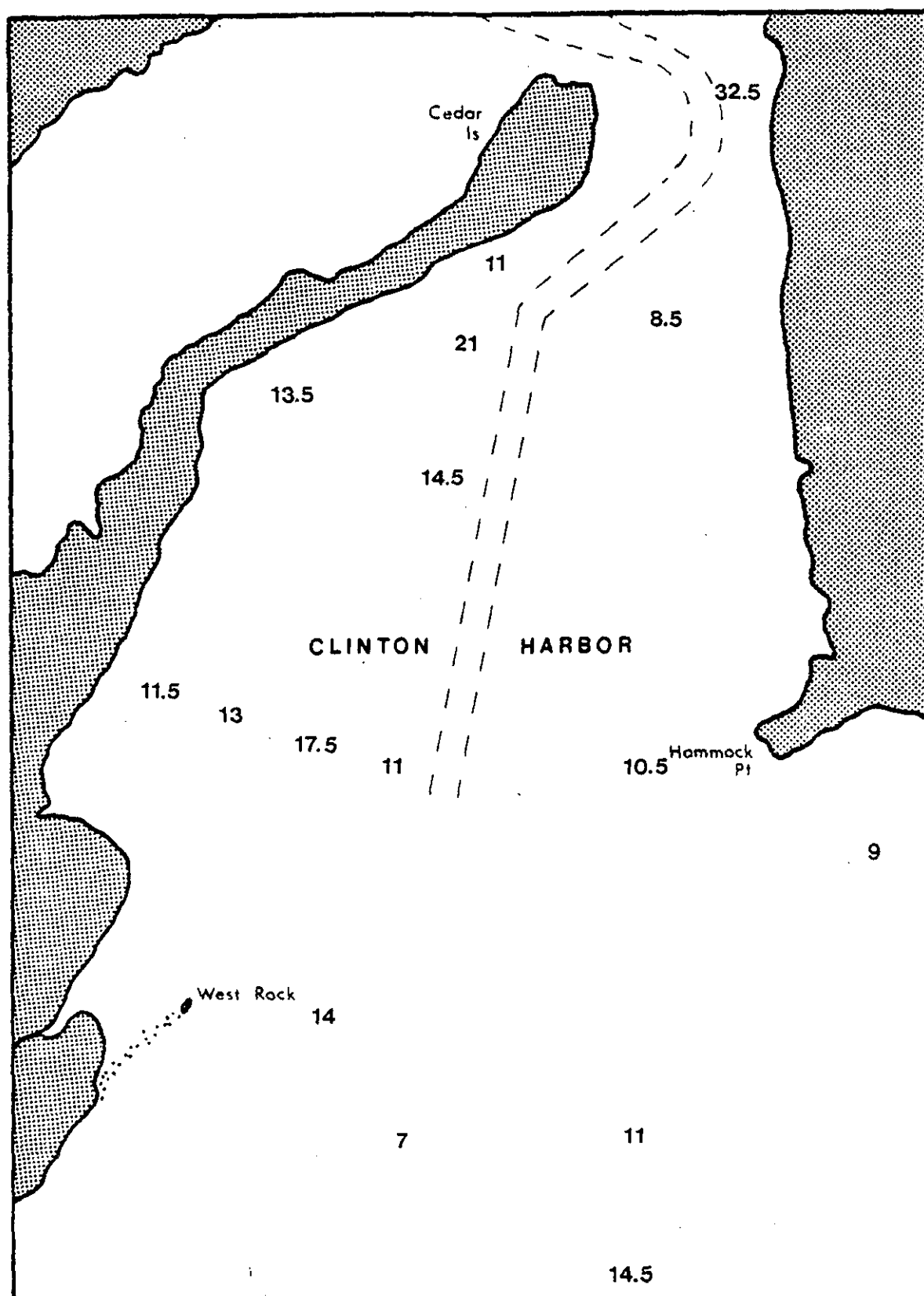
Figure 2. Mean number of benthic species per 0.04m^2 replicate, September 1981.
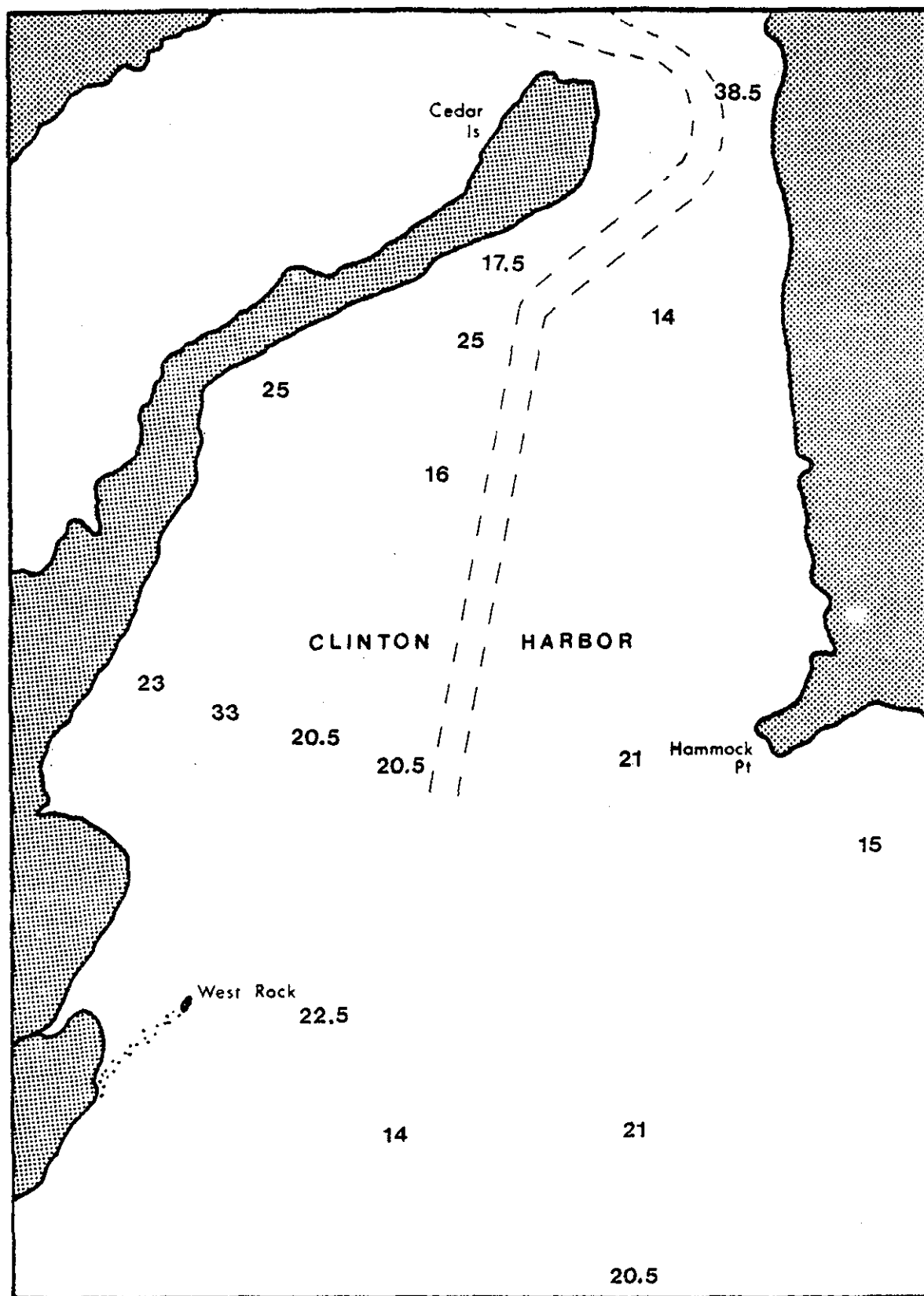
Figure 3. Mean number of benthic species per 0.04m^2 replciate, October 1981.
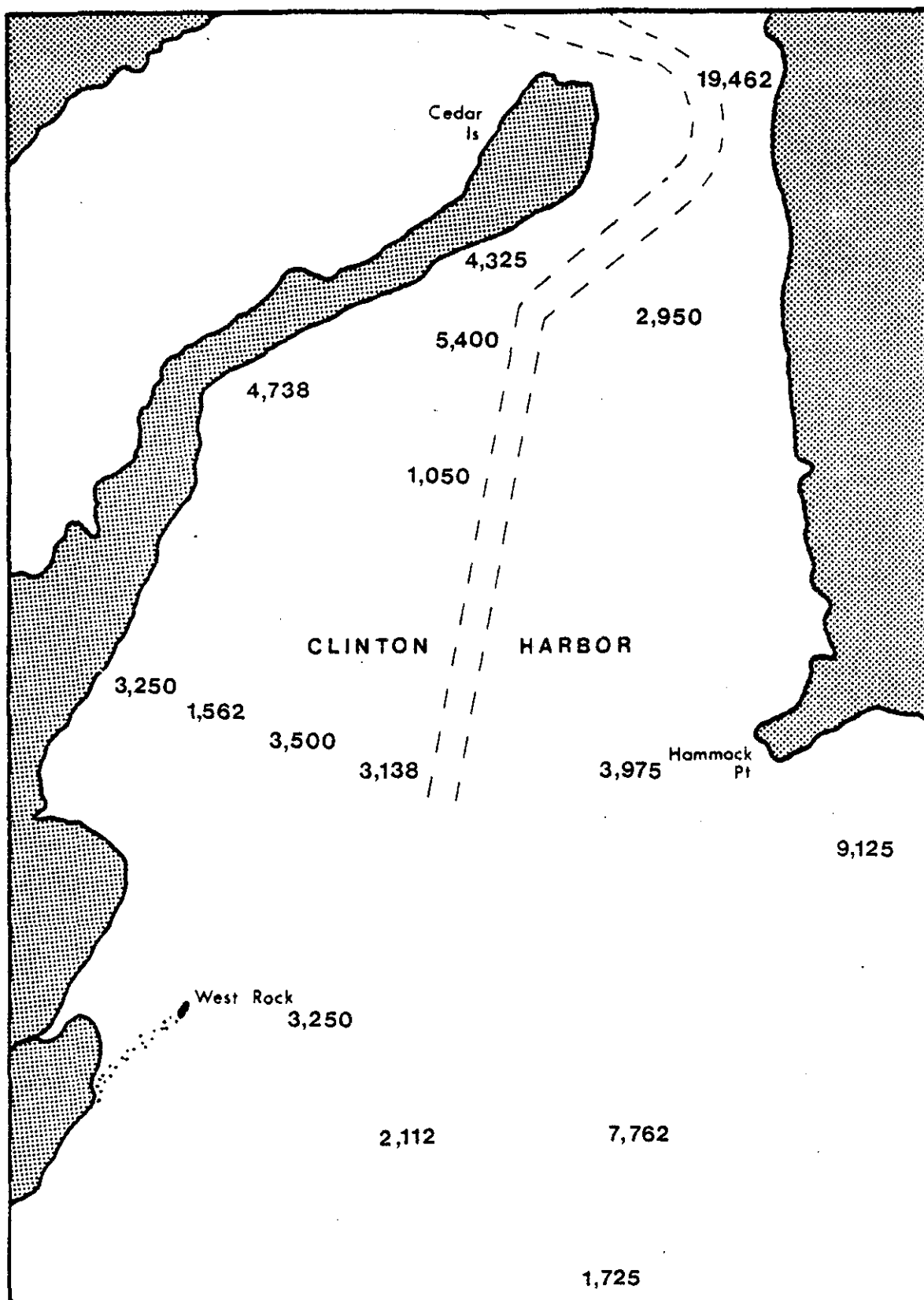
Figure 4. Benthic invertebrate density per square meter, September 1981.
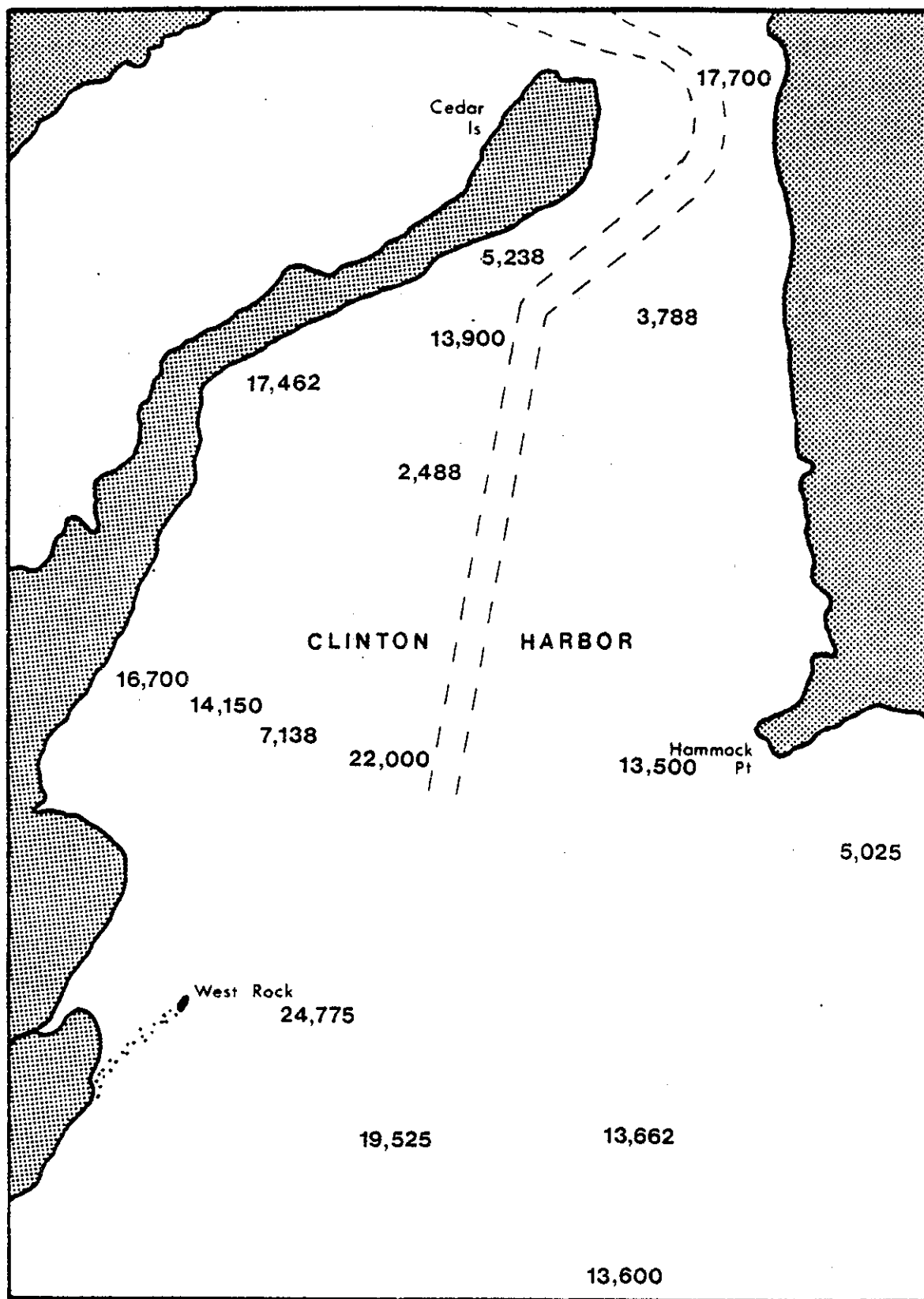
Figure 5. Benthic invertebrate density per square meter, October 1981.

By October, densities had increased at most stations, in some cases by nearly an order of magnitude. Greater densities were found at Station 5, with 24,775 individuals/m^2 while Station 15 was again the least densely populated at 2,488 individuals/m^2. Station 14, which had the highest densities in September showed a slight decrease to 17,700/m^2. Overall, 14 of the 16 stations had an increase in faunal density between September and October.

2.2.4 Diversity

Shannon-Wiener diversity values (H') are shown in Figure 5a for the September sampling and Figure 5b for October. September diversities were highly variable, ranging from a low of 0.71 at Station 3 to 3.43 at Station 15. Diversities within the proposed disposal area had higher diversity than the remainder of the harbor ($\bar{x}$ = 2.63 vs. 1.94).

October diversities were much more uniform and varied from a low of 1.32 at Station 6 to 3.18 at Station 16. Although those stations within the disposal area again had higher mean diversity ($\bar{x}$ = 2.70 vs. 2.44), the difference was much less than that seen in September.

These diversity values are generally higher than those recorded from nearby harbors with greater anthropogenic impacts. In a recent study of Black Rock Harbor and Bridgeport Harbor using similar methodology (McGrath, 1981), diversities in many areas were found to be less than 1.00 and many stations were azoic at 0.5 mm. Such low diversities, indicating severe stresses, were not approached at Clinton, except at a few stations where elevated populations of a single species produced artificially depressed diversities due to decreased evenness.

Diversities at Clinton were also greater than those typically recorded from a very extensive study of New Haven Harbor (Hartzband, et al., 1979) in which diversity values greater than 2.00 were unusual, even at stations considered to be "controls." Again, this difference is largely attributable to the relative lack of pollution-related impacts at Clinton.

2.2.5 Community Classification

The results of the normal, or Q-mode, classification analysis for the September sampling are presented in the form of a hierarchical dendrogram in Figure 6. In most cases, the two replicates from each station grouped together and it is possible to discern four site groups from the dendrogram.

The first, and most cohesive, group is at the bottom of the dendrogram and includes the offshore Stations (1, 2, 3, 4) lying outside of the harbor proper.
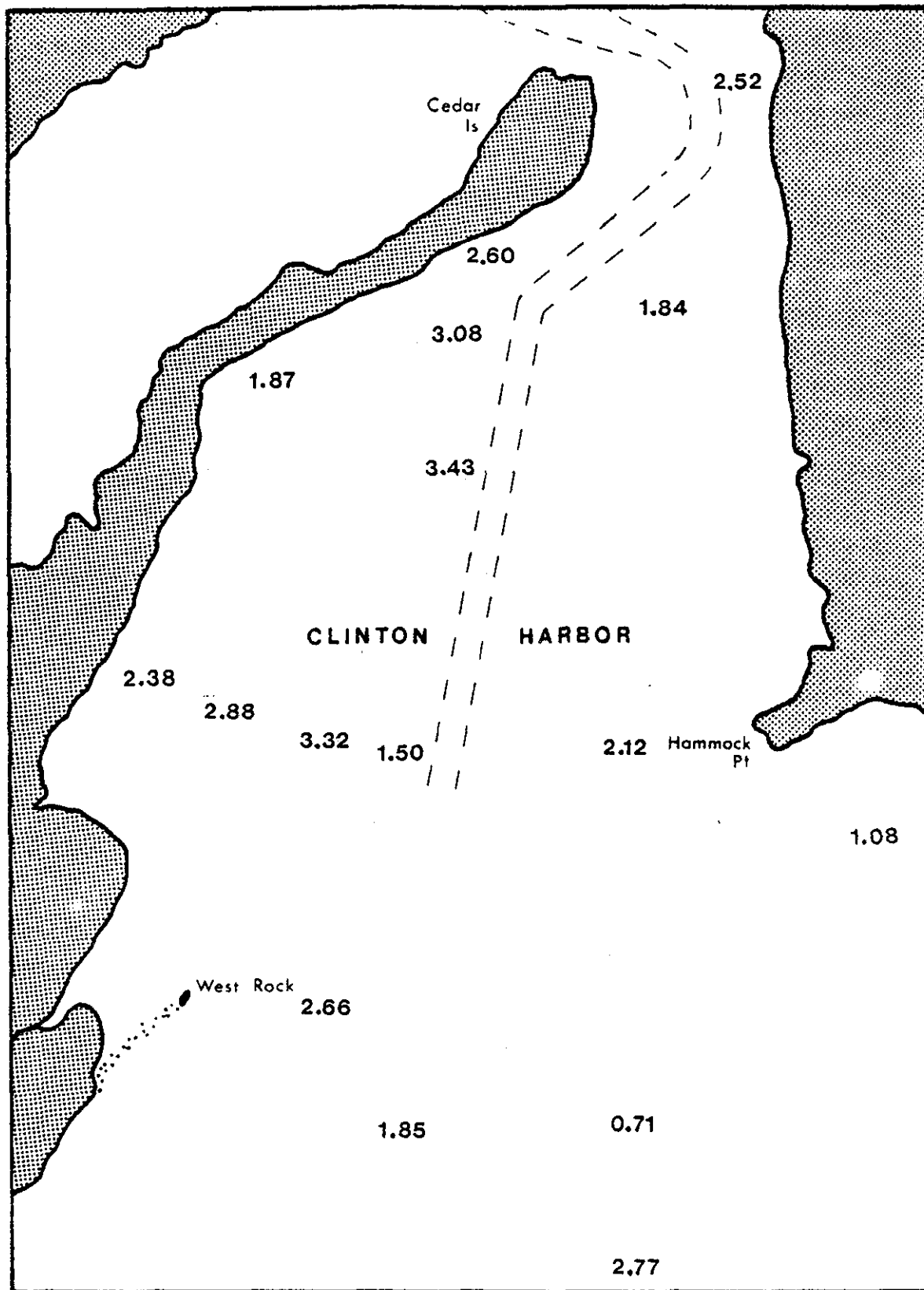
Figure 5a. Shannon-Wiener diversity values, September 1981.
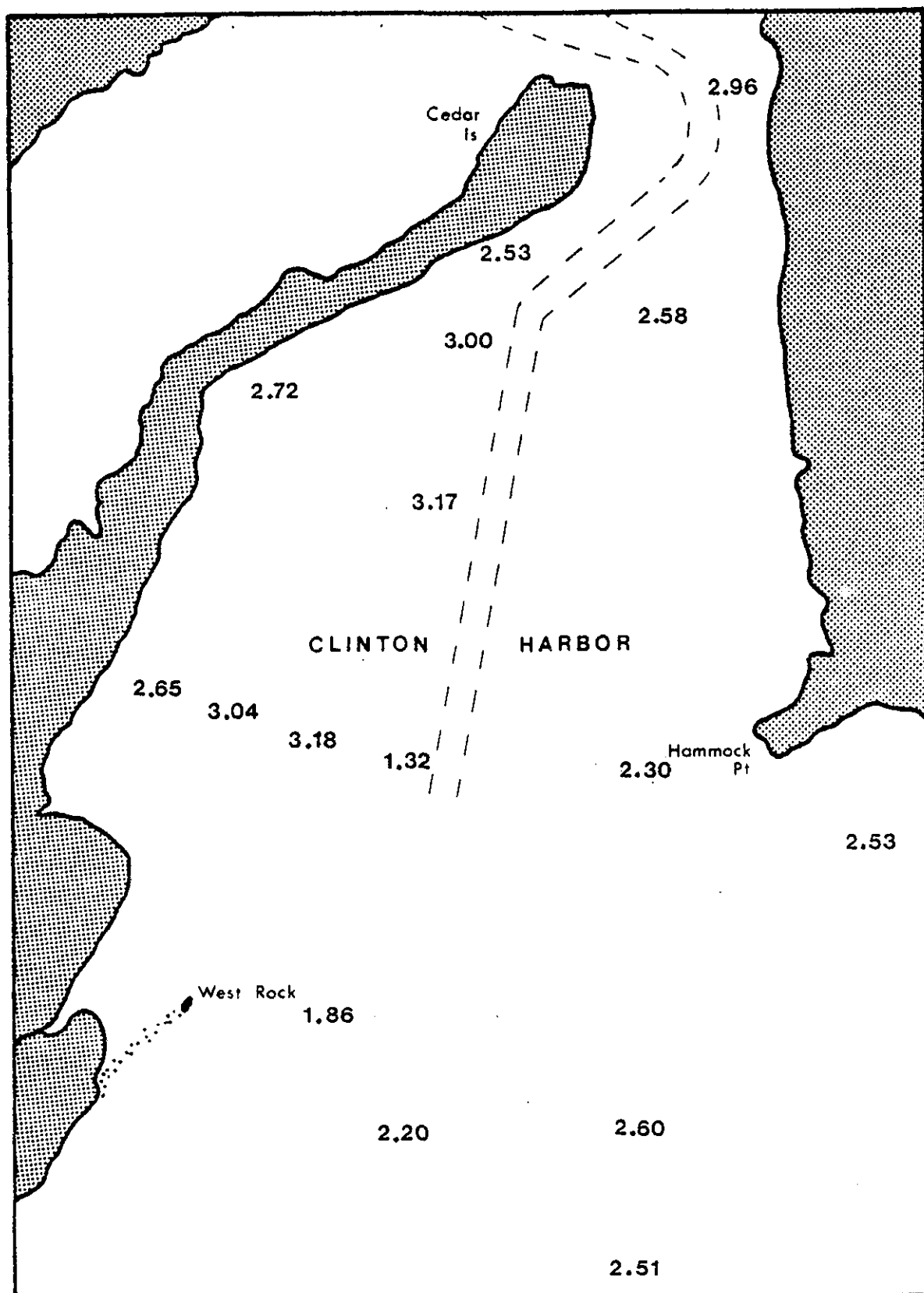
Figure 5b. Shannon-Wiener diversity values, October 1981.
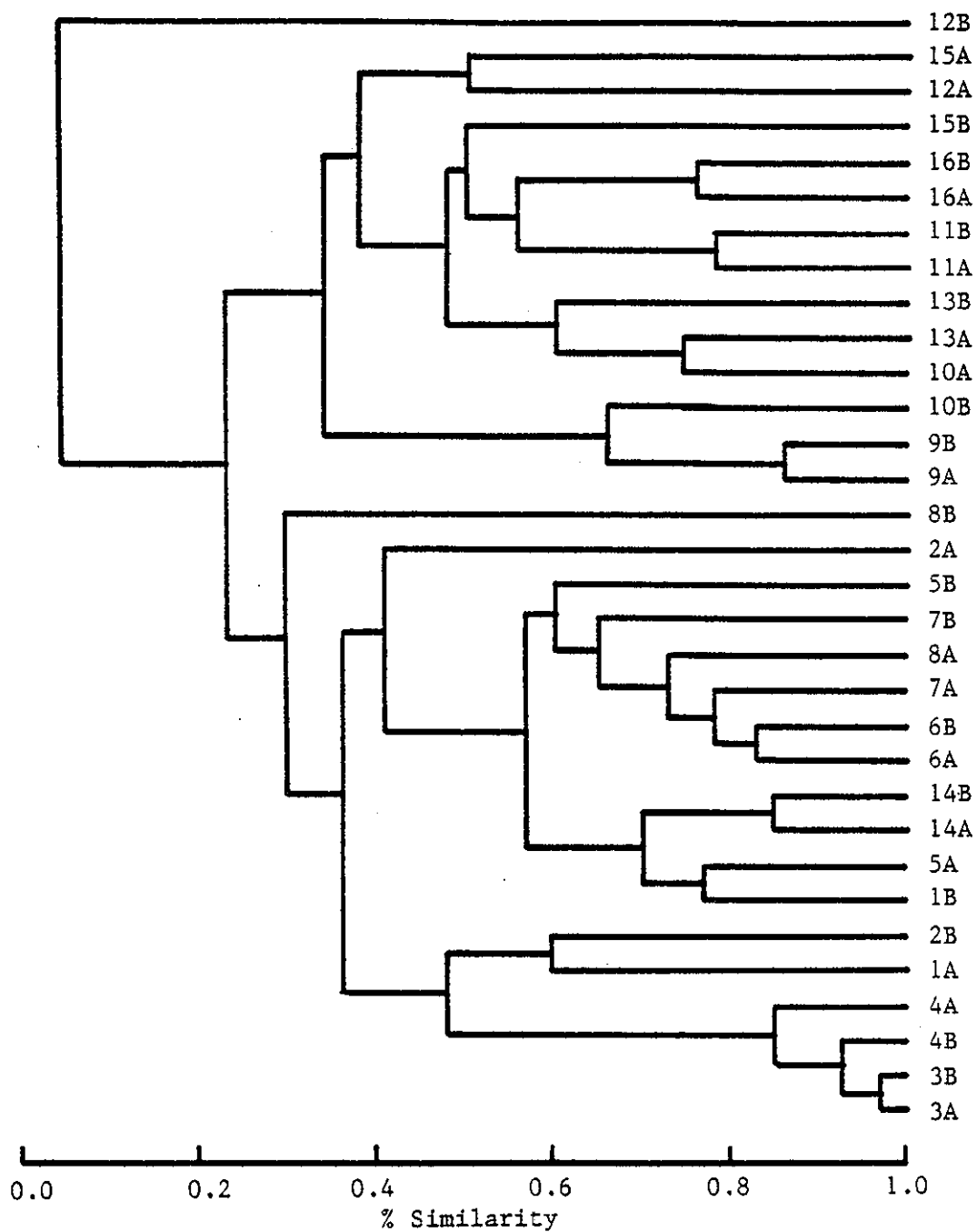
Figure 6.   Hierarchical dendrogram, Bray-Curtis similarity and group-average sorting, September data. Normal or Q-mode.

A second group included those samples between 1B and 5B in Figure 6. This cluster, termed Group 2, was defined as Stations 5, 6, 7, 8 and 14. As may be seen from Figure 7, these are located along the channel at the outer boundary of the proposed disposal area, except for Station 14 which is at the boundary of the inner and outer harbors. A third cluster, Group 3, occurs in the dendrogram immediately above this group and contains Stations 9 and 10. As indicated in Figure 7, these occupy the intertidal or shallow subtidal region of the disposal area.

The final cluster includes samples between 10A and 15A at the top of the dendrogram. Incorporating the data on station location and the complete species lists, this cluster (Group 4) was defined as Stations 11, 13, 15 and 16. These generally occupy the subtidal bottom of the proposed disposal area.

In order to investigate further the faunistic associations which characerize each of these station clusters, an inverse, or R-mode, analysis was run on the same data matrix. The results are shown as a hierarchical dendrogram in Figure 8 and the discernable species groups are listed in Table 4. As is often the case in an R-mode analysis, the species groups are less well-defined than in the Q-mode analysis of the same matrix, and the interpretation of the dendrogram is necessarily more subjective.

The two dendrograms were combined in a nodal analysis by calculating the percentage of occurrences for each species group within each station group. For example, the intersection of a seven-member species group with a five-member station group would have 35 possible occurrences, if each species were present at each station. If the total number of occurrences were, in fact, 30 of 35, the score at that intersection (node) would be 85.7%. Nodes with elevated values indicate that a species group is associated with a particular station group. The nodal analysis for the September sampling is presented in Figure 9.

Station group 1, including the deeper offshore stations, was characterized primarily by species group II (66.7%) and, to a lesser extent, group I (38.1%). These two groups include many species which are characteristic of soft mud bottoms in Long Island Sound and include Nucula proxima and Nephtys incisa, the classic Nucula-Nephtys assemblage described by Sanders (1960).

Species group II, comprising only Nephtys and the mud snail Nassarius trivittatus was common only at station group 1 but species group I was also found at station group 2, the deeper stations in the outer harbor area. This station group included most of the species groups to some extent but was primarily characterized by species groups I, III and V.
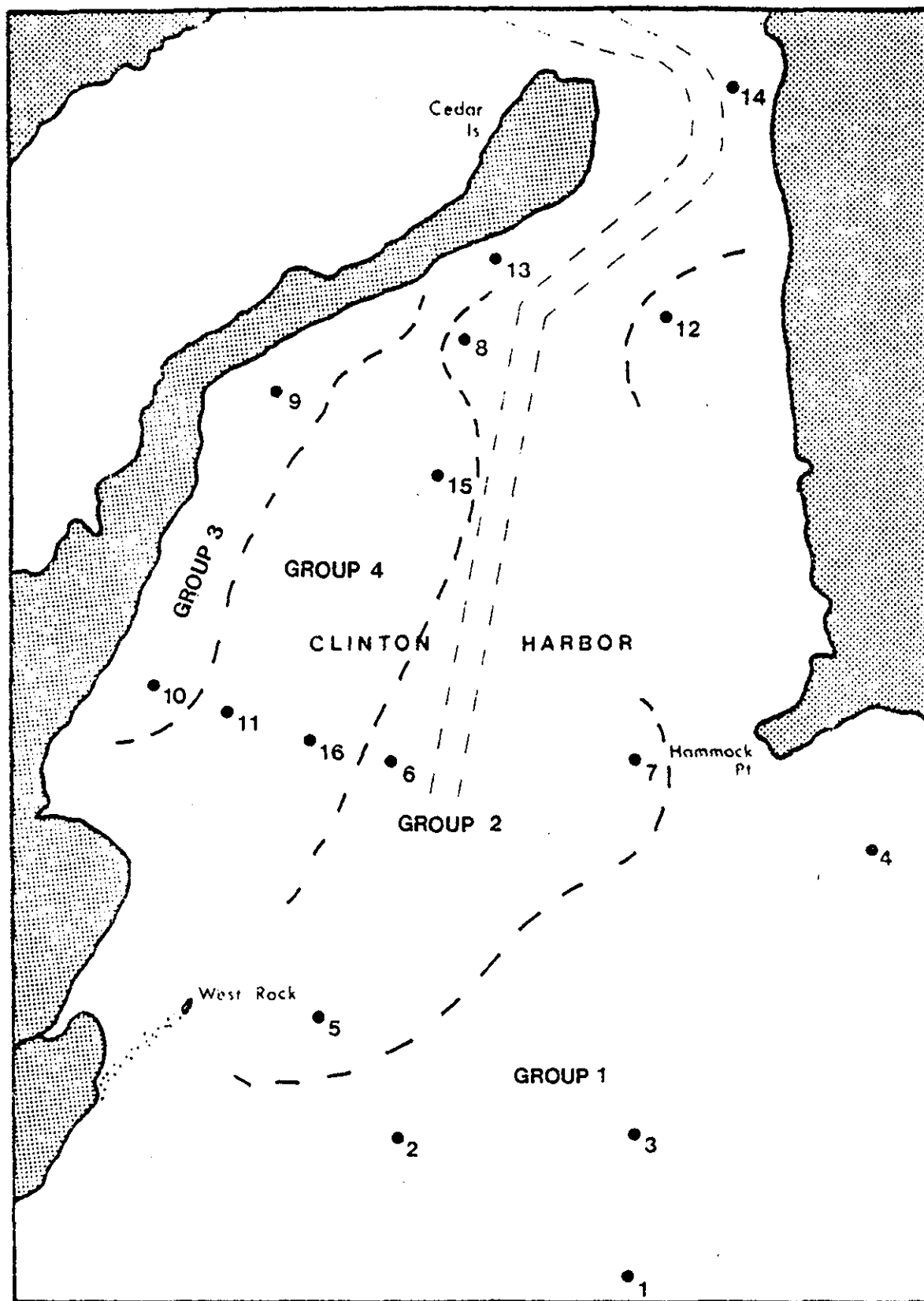
Figure 7. Approximate distribution in the harbor of station groups identified from the normal classification analysis, September data.
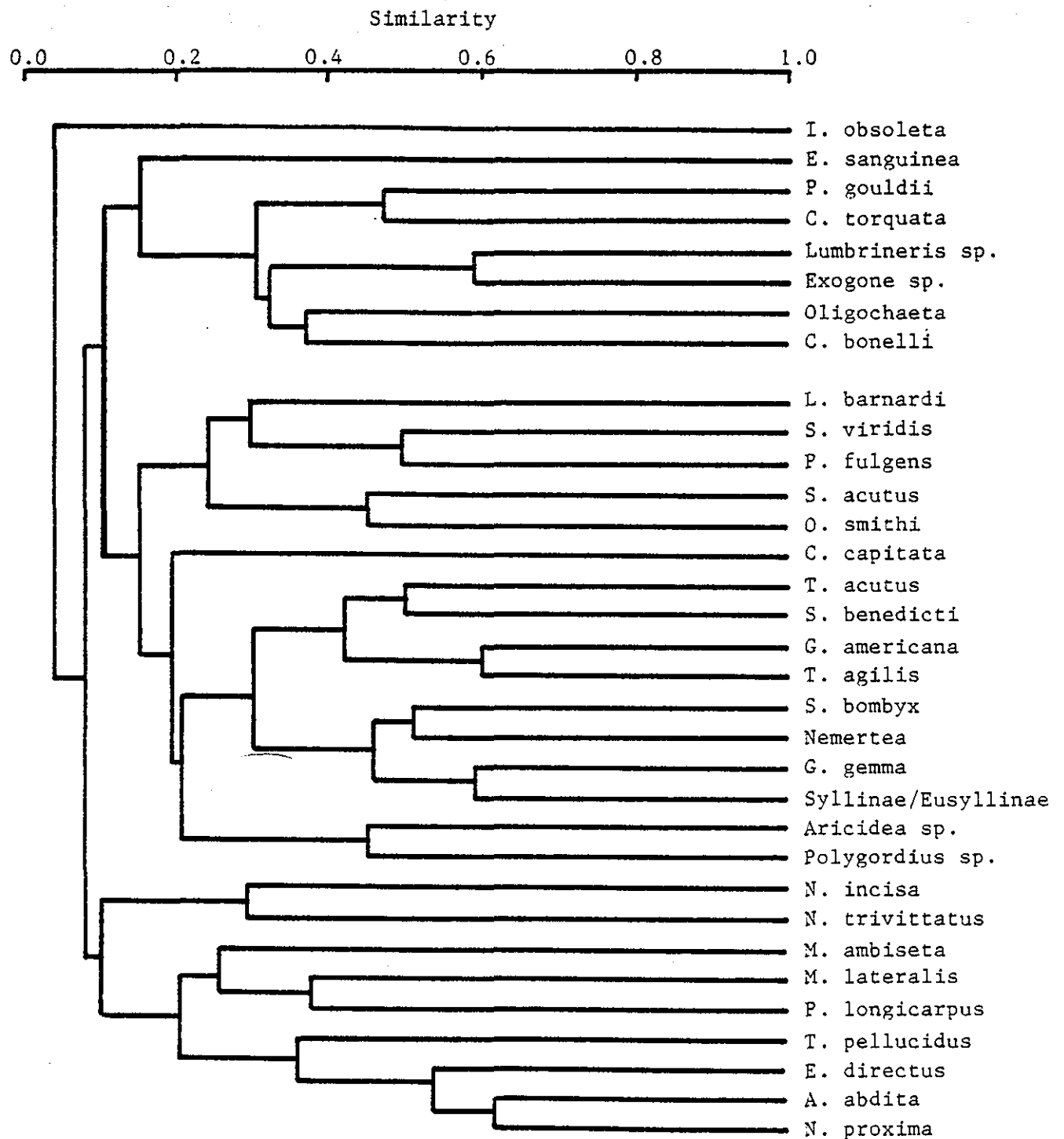
Figure 8. Hierarchical dendrogram, Bray-Curtis similarity and group-average sorting, September data. Inverse or R-mode.

TABLE 4

SPECIES GROUPS IDENTIFIED FROM INVERSE CLASSIFICATION
ANALYSIS, SEPTEMBER DATA

Group I	Group II	Group III
Nucula proxima	Nassarius trivittatus	Polygordius spp.
Ampelisca abdita	Nephtys incisa	Aricidea sp.
Ensis directus		Syllinae/Eusyllinae
Tubulanus pellucidus		Gemma gemma
Pagurus longicarpus		Nemertea
Mulinia lateralis		Spiophanes bombyx
Mediomastus ambiseta		Tellina agilis
		Glycera americana
		Streblospio benedicti
		Tharyx acutus
		Capitella capitata

Group IV	Group V
Oxyurostylis smithi	Corophium bonelli
Scoloplos acutus	Oligochaeta
Paraonis fulgens	Exogone sp.
Scolecolepides viridis	Lumbrineris sp.
Listriella barnardi	Clymenella torquata
	Pectinaria gouldi

SPECIES GROUPS

	I	II	III	IV	V
1	38.1	66.7	19.7	6.7	11.1
2	50.0	12.5	43.9	16.7	37.5
3	7.1	0.0	72.7	75.0	8.3
4	10.0	10.0	60.9	40.0	16.7

STATION GROUPS

Figure 9. Results of nodal analysis for September data. Results are expressed as percent of possible occurrences at each station group/species group intersection. For composition of groups, see text.

Station group 3 comprised Stations 9 and 10 and is believed to be representative of the lower intertidal and shallow subtidal areas of the proposed disposal site. The communities in this area were characterized by a high level of occurrence of species from species groups III and IV. Species group III was widespread throughout the outer harbor area and included most of the species described earlier as dominants: Tellina, Streblospio, Glycera, Tharyx, etc.

Species group IV appeared to contain species which were found primarily in the shallow subtidal and were present primarily at station group 3. These included the polychaetes Paraonis and Scoloplos, and the amphipod Listriella.

Most of the proposed disposal area was contained within station group 4 which included Stations 11, 12, 13, 15 and 16. These stations form a contiguous broad band between the outer zone of station group 2 and the inner zone of station group 3. This area contained primarily species from species groups III and IV, but group IV was considerably less common here than at the more inshore stations.

In summary, the September sampling indicated four basic faunal provinces within the study area. One of these occupied the deeper offshore muds beyond the harbor proper and was occupied by a "typical" Long Island Sound soft-bottom community. A second area, comprising the shallow subtidal zone of the proposed disposal area was occupied by a community wholly different from that found offshore; species which were common at one location tended to be absent from the other. The majority of the disposal area was occupied by a community which was very closely related to that seen in the shallow subtidal but which also contained species generally not seen further inshore. Finally, the deeper areas of the outer harbor contained a community which comprised components of the other three community types.

The results of the classification analysis of the October data were, with some exceptions, generally comparable with the results from September. The results of the normal classification are presented as a hierarchical dendrogram in Figure 10 and the resultant clusters are plotted in Figure 11. The station clusters derived from this analysis were generally more distinct than those seen from September and some stations (e.g., 8 and 12) did not group with any cluster.

Again, four basic station groupings were discernable from the dendrogram. The first of these, incorporating those samples between 3A and 4A (see Figure 10) is analogous to station group 1 from the September sampling and includes offshore stations 2, 3 and 4. Station 1 was not included in this offshore group in the October sampling.
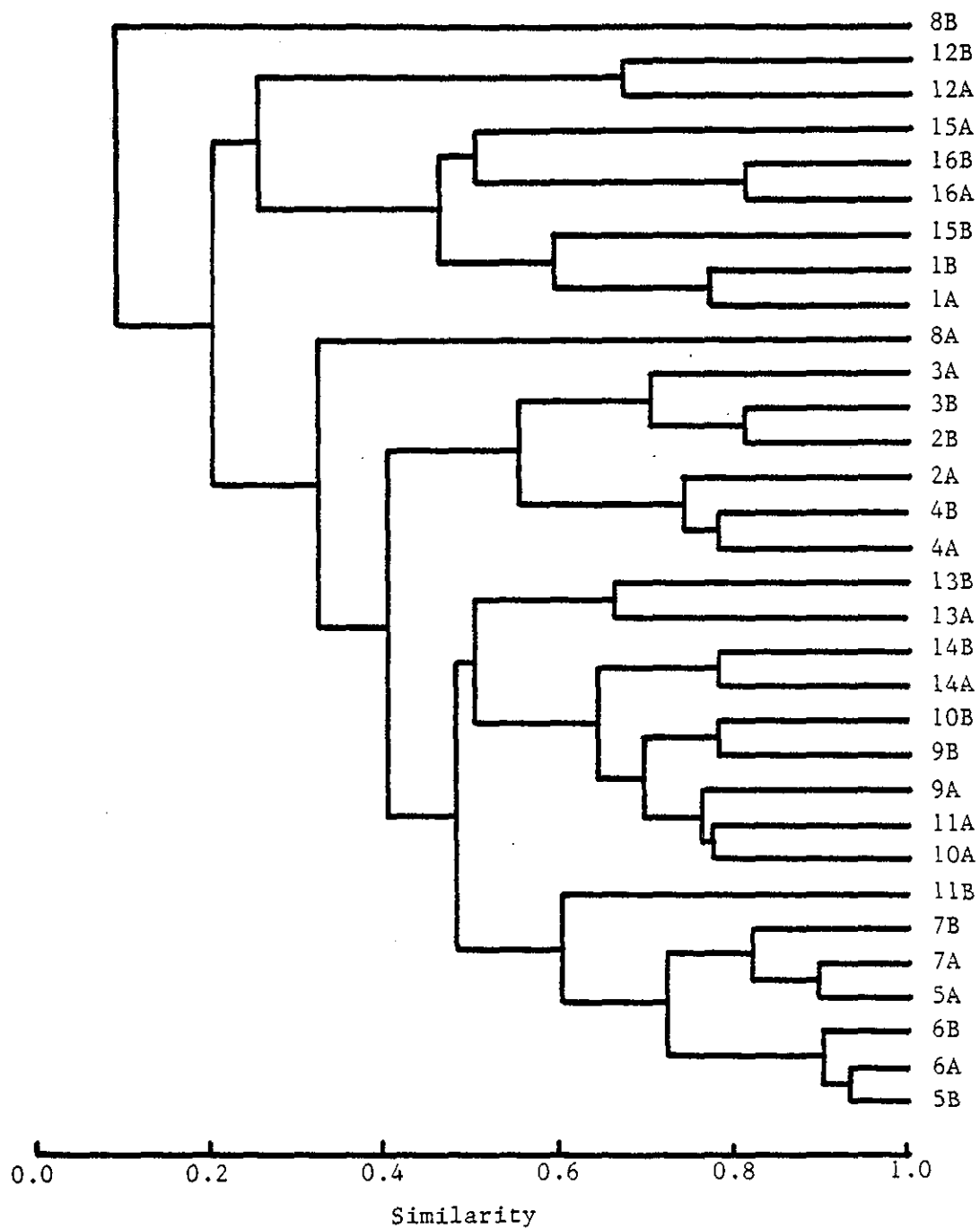
Figure 10.   Hierarchical dendrogram, Bray-Curtis similarity and group-average sorting, Ocotober data. Normal or Q-mode.
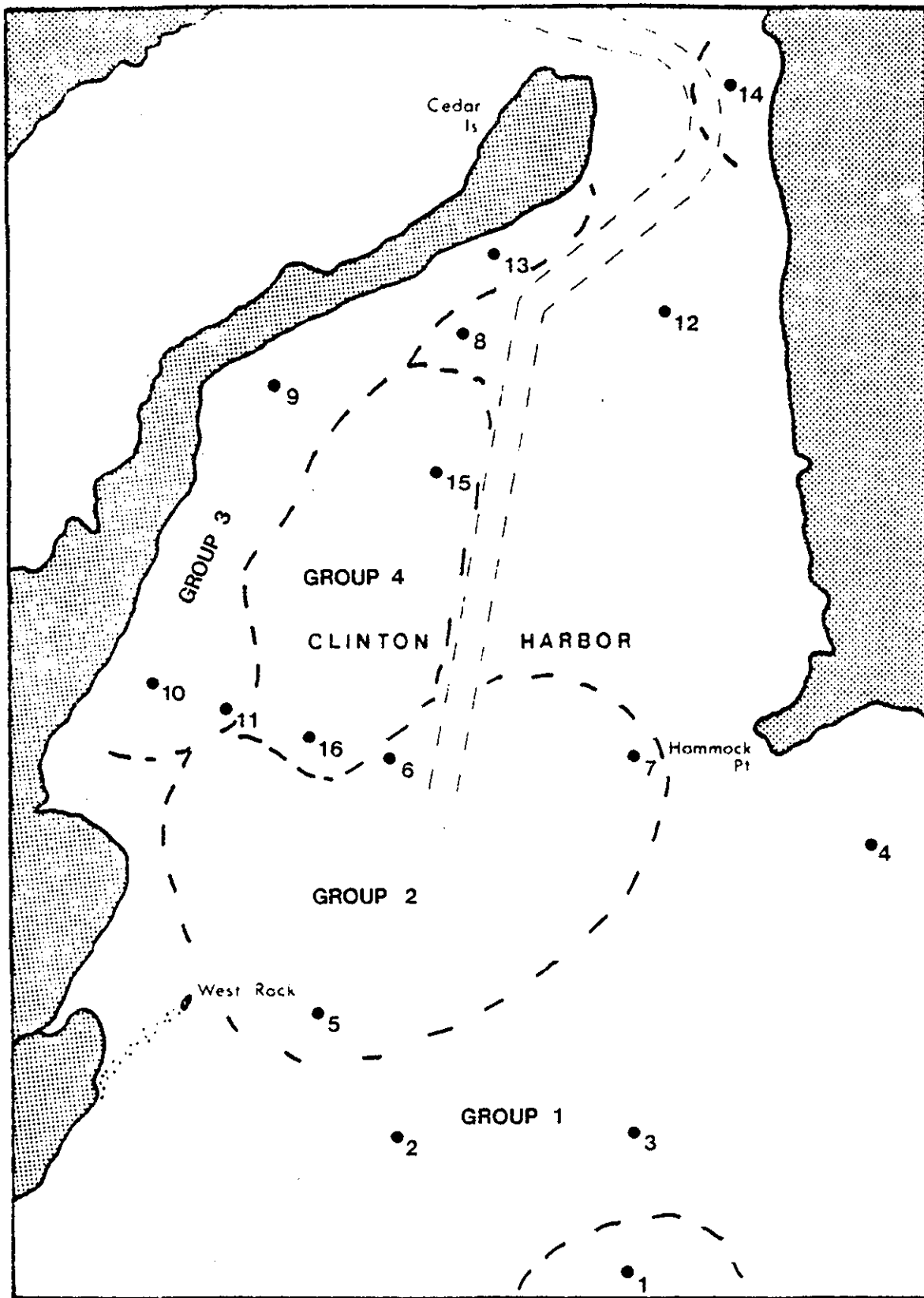
Figure 11.   Approximate distribution in the harbor of station groups identified from the normal classification analysis, October data.

Station group 2, again analogous to group 2 in September, included samples between 5B and 11B at the bottom of the dendrogram. Stations included in this group were 5, 6 and 7. This is similar to the composition of group 2 from September with the exception of Stations 8 and 14.

Station group 3, comprising the area of the dendrogram between samples 10A and 13B, included stations 9, 10, 11, 13 and 14 and occupied the intertidal and shallow subtidal area of the disposal site. This distribution is generally similar to that of group 3 from September with the inclusion of stations 13 and 14.

Finally, the central area of the proposed disposal site is occupied by station group 4 which includes stations 15 and 16. Although noticeably reduced in extent as compared with the September results, this group occupies the same general area as the earlier group 4. In addition, group 4 in October included station 1, which had previously been clustered with group 1. The anomalous clustering of station 1 appears to be due to sediment, in that the sediment at this station in October was unusually coarse; this may indicate the presence of small-scale sediment patchiness in this area.

The October data matrix was also analyzed in R-mode and the results are presented as a dendrogram in Figure 12. The dendrogram produced six very weak clusters and the component species of these are listed in Table 5. The two dendrograms from October were combined in a nodal analysis as shown in Figure 13 in order to investigate the spatial distribution of the species groups. The reason for the weak clustering was immediately apparent: most of the species groups were found to occur in more than one station group.

Station group 1, comprising the soft offshore sediments, was characterized by the presence of species group IV and V and the pronounced absence of the species group I. This is generally consistent with the September results since group V contains many of the components of group I from September (i.e., _Mulinia_ _lateralis_, _Nucula_ _proxima_, _Tubulanus_ _pellucidus_). Group IV, however, is similar to group III from September, and comprises species which were generally absent from this area during the first survey. It appears that a shift toward coarser sediments in this area may be responsible for this result.

Station group 2, in the deeper central area of the harbor, again demonstrated no strong affinity for one particular species group but rather contained most of the species groups at a high level of occurrence. The most characteristic species group in this area, group IV, was present in all areas of the harbor in October, and included many of the species identified earlier as dominants.
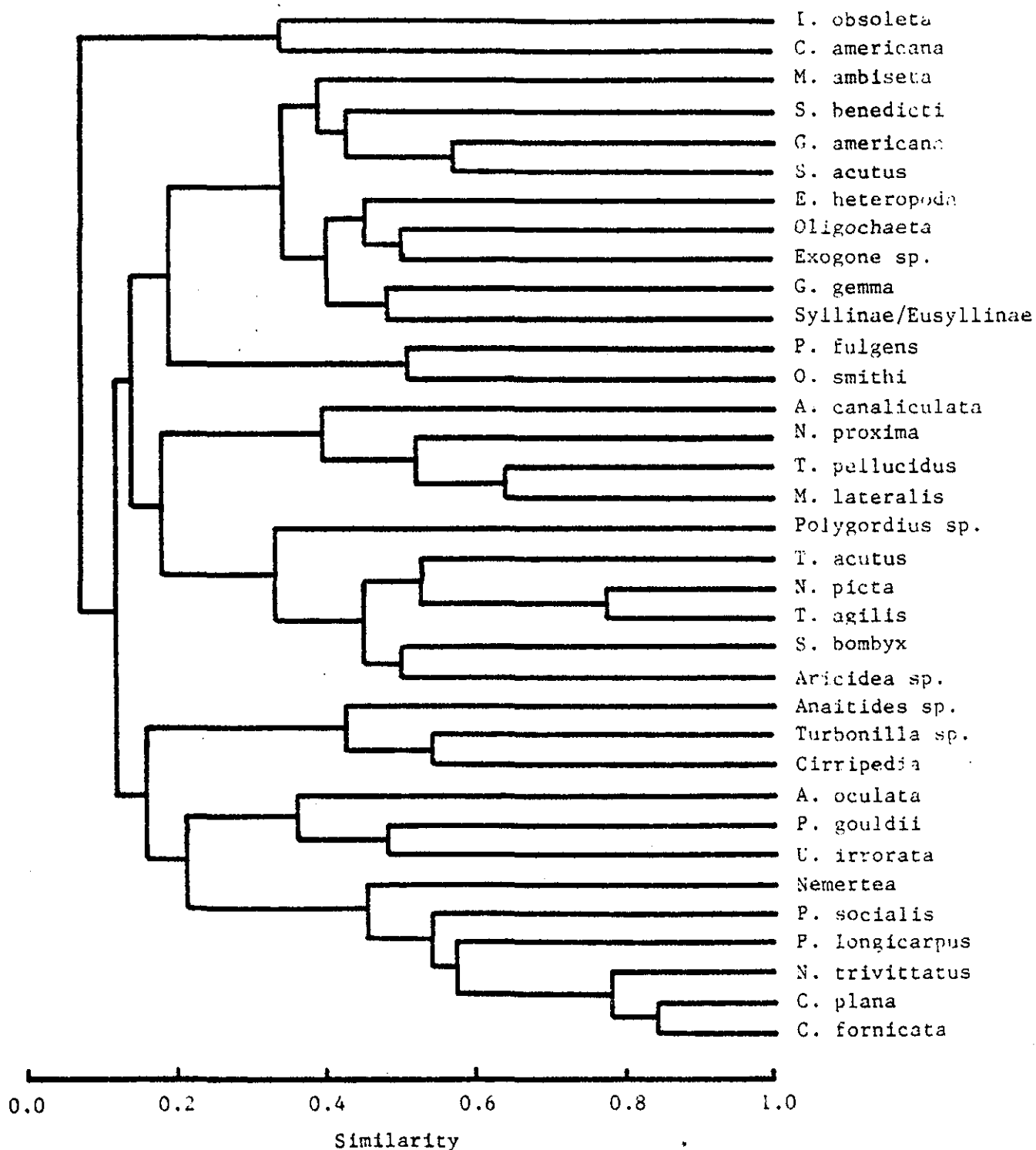
Figure 12.   Hierarchical dendrogram,   Bray-Curtis   similarity   and   group-average
sorting, October data.   Inverse or R-mode.

TABLE 5

SPECIES GROUPS IDENTIFIED FROM INVERSE CLASSIFICATION
ANALYSIS, OCTOBER DATA

Group I	Group II	Group III
Crepidula fornicata	Unciola irrorata	Cirripedia
Crepidula plana	Pectinaria gouldii	Turbonilla sp.
Nassarius trivittatus	Asabellides oculata	Anaitides sp.
Pagurus longicarpus		
Polydora socialis		
Nemertea		

Group IV	Group V	Group VI
Aricidea sp.	Mulinia lateralis	Syllinae/Eusyllinae
Spiophanes bombyx	Tubulanus pellucidus	Gemma gemma
Tellina agilis	Nucula proxima	Exogone sp.
Nephtys picta	Acteocina canaliculata	Oligochaeta
Tharyx acutus		Eteore heteropoda
Polygordius spp.		Scoloplos acutus
		Glycera americana
		Streblospio benedicti
		Mediomastus ambiseta

SPECIES GROUPS

	I	II	III	IV	V	VI
1	13.9	38.9	22.2	63.8	83.3	40.7
2	22.2	61.1	55.6	83.3	58.3	46.3
3	38.3	40.0	33.3	63.3	25.0	84.4
4	25.0	12.5	12.5	79.2	34.4	50.0

STATION GROUPS

Figure 13.   Results of nodal analysis for October data. Results are expressed as percent of possible occurrences at each station group/species group intersection. For composition of groups, see text.

Station group 3, along the shoreline of the proposed disposal area, also included all of the species groups in at least moderate abundance, but with relative occurrences that were different from group 2. Species groups which were very abundant at groups 1 and 2 were markedly less common here, particularly species group IV, which was characteristic of the offshore muds. In contrast, species group VI, which was present in only moderate abundance at the earliest areas, was very common inshore. This group was very similar to group III in September which was also most common at these shallow inshore stations.

The final station group, group 4, occupies the central area of the disposal site and is characterized by high percentages of occurrence of species group III and moderately high occurrence of group VI. In this respect, these stations are intermediate between the inshore and offshore areas in faunal composition as well as location.

In summary, due to the generally increased species richness and faunal density in October, it was more difficult to arrive at a clear correspondence between station groups and species groups. The pattern of station groups was very similar to that seen in September: an offshore group of stations, a shallow subtidal group occupying the extreme inshore area of the disposal site, a third station cluster located in the central area of the disposal site, and a group of stations occupying the deepest area of the harbor. Although some individual stations, particularly those at the group boundaries, changed groups between samplings, the general pattern is consistent.

The great increase in species from September to October complicated the difficulty of establishing correspondence between species groups from the first sampling with groups from the second. In each case, however, it was possible to identify one group as characteristic of each of the first three station clusters. Although individual species changed groups between samplings, the overall pattern was consistent. Thus, species group I in September and group IV in October were most common at the offshore station group and include the characteristic soft-bottom species Mulinia, Nucula and Tubulanus. Group VI in October was extremely common at the shallow stations along the shoreline of the disposal area; this species group included many of the components of groups III and IV in September (Syllinae/Eusyllinae, Gemma gemma, Oligochaeta, etc.) which were also characteristic of this area in September.

Group 4, occupying the middle of the disposal area was characterized by species group III in September and group IV in October. Both of these groups contain Aricidea, Spiophanes, Tellina and Tharyx, indicating a high degree of consistency between the two surveys. Station group 2, in the deeper areas of the harbors, contained components of several species groups during both sampling periods.

2.2.6 Sediments

Summary sediment statistics for the September and October samplings are presented in Tables 6 and 7. Sediments during the September sampling ranged from soft silt-clay facies (e.g., Stations 2 and 4) to coarse gravelly sands (e.g., Stations 15 and 16). One of the more important properties of a sediment in terms of the types of infaunal populations it is capable of supporting is the silt-clay content. The percentage of silt-clay throughout the harbor is shown in Figure 14. Four sediment classes were arbitrarily selected based on what appeared to be natural discontinuities in the data.

The offshore stations, including Stations 1, 2 and 4 had sediments containing more than 40% silt-clay. Immediately inshore of this there was an area of elevated silt-clay (10-40%) occupying the deeper central area of the outer harbor and including Station 14 near the inner harbor boundary. Most of the shallower areas of the outer harbor, and virtually all of the proposed disposal area, had sandy sediments with less than 5% silt-clay. Only three stations, along the northern and southern boundaries of the disposal area, fell in the 5-10% silt-clay category.

During October, sediments from nearly every station were coarser than in September and contained less silt-clay. This was true both in the shallow and deep areas of the harbor and for the offshore mud strata. The percent of silt-clay is shown in Figure 15, using the same categories developed for Figure 14. Only Station 4 had more than 40% silt-clay; Station 2, which previously had elevated silt-clay (83.5%) was reduced to only 31.7% and sediment at Station 1 (56.5% silt-clay in September) had changed to a medium sand strata with only 4.8% silt-clay. Sediments with less than 5% silt-clay were more widely distributed in October, and most areas of the outer harbor were in this category.

Observations of sediment ripple patterns and calculations of minimum shear velocities presented in Section II of this report indicate significant sediment instability in the harbor and the tidal velocities described in Section I are at or near the magnitudes necessary for large-scale sediment transport. It is not surprising, then, that widespread sediment changes occurred between the two samplings and presumably such changes are a natural part of the Clinton Harbor ecosystem.

32

TABLE 6

SEDIMENT GRAIN-SIZE PARAMETERS
SEPTEMBER SAMPLING

Station-Replicate	Median (mm)	% Silt-Clay
1-A	.039	57.2
1-B	.043	56.1
2-A	.012	93.3
2-B	.020	74.4
3-A	.149	18.0
3-B	.148	21.2
4-A	.013	91.2
4-B	.019	77.6
5-A	.195	8.9
5-B	.189	6.1
6-A	.095	29.4
6-B	.103	24.2
7-A	.083	24.0
7-B	.077	35.9
8-A	.370	8.7
8-B	.226	5.2
9-A	.164	6.0
9-B	.180	3.1
10-A	.190	2.4
10-B	.199	3.7
11-A	.186	2.5
11-B	.195	2.7
12-A	.193	1.5
12-B	.190	1.7
13-A	.168	10.5
13-B	.166	6.5
14-A	.098	25.3
14-B	.068	46.3
15-A	.240	1.2
15-B	.252	1.5
16-A	.308	1.8
16-B	.301	1.8

TABLE 7

SEDIMENT GRAIN-SIZE PARAMETERS
OCTOBER SAMPLING

Station-Replicate	Median (mm)	% Silt-Clay
1-A	.170	5.8
1-B	.250	3.9
2-A	.037	58.6
2-B	.244	4.9
3-A	.150	10.6
3-B	sample not taken	----
4-A	.016	80.5
4-B	.004	74.5
5-A	.191	6.3
5-B	.194	3.5
6-A	.164	3.1
6-B	.152	12.5
7-A	.118	4.0
7-B	.132	5.5
8-A	.295	11.3
8-B	.406	11.2
9-A	.141	24.1
9-B	.255	12.2
10-A	.954	1.0
10-B	.711	1.7
11-A	.991	1.9
11-B	2.153	1.6
12-A	.194	1.4
12-B	.194	1.7
13-A	.179	4.1
13-B	.182	4.5
14-A	.105	18.8
14-B	.093	25.8
15-A	.212	1.4
15-B	.185	1.4
16-A	.330	1.6
16-B	.332	1.2
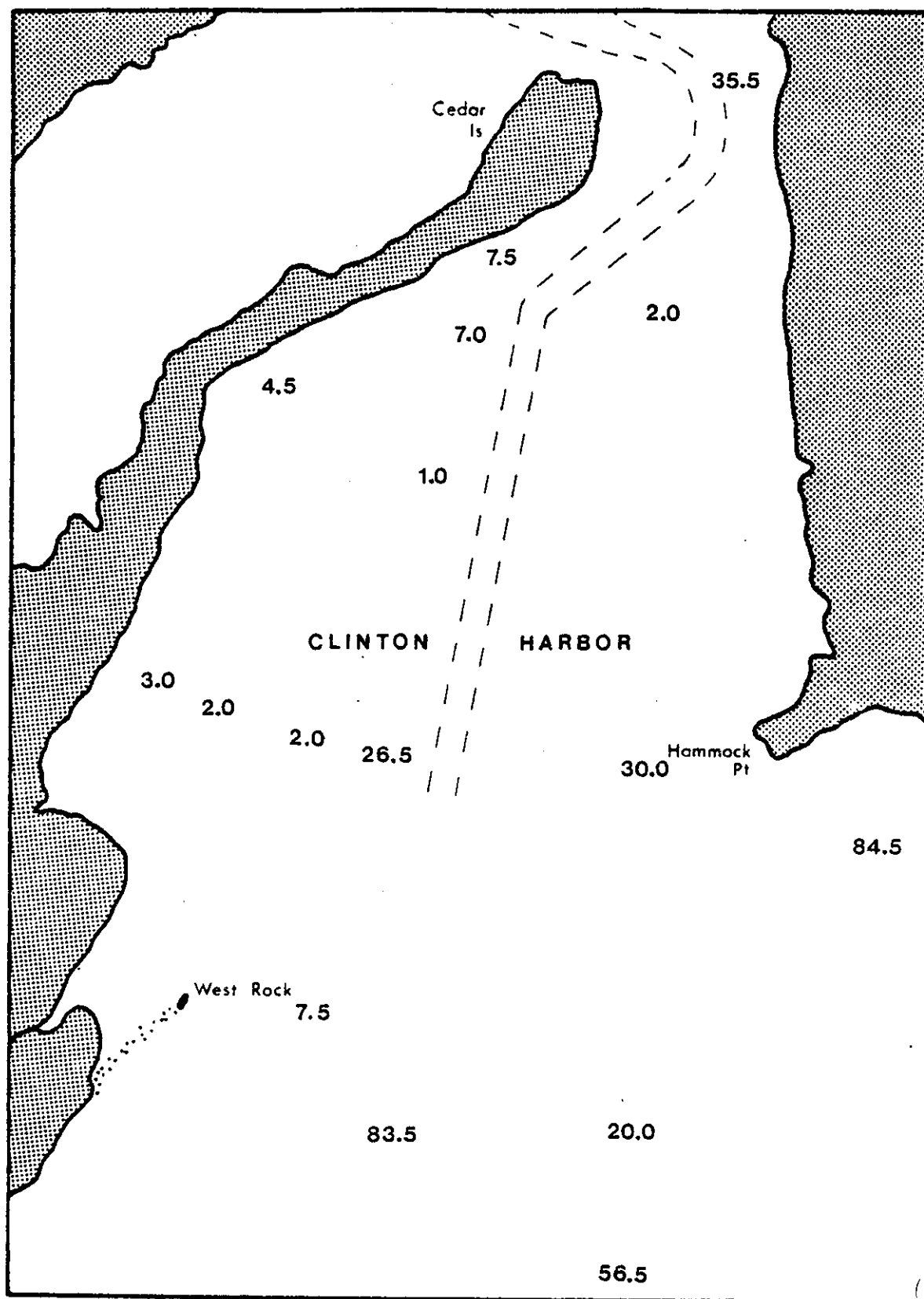
Figure 14. Sediment percent silt-clay, September sampling.
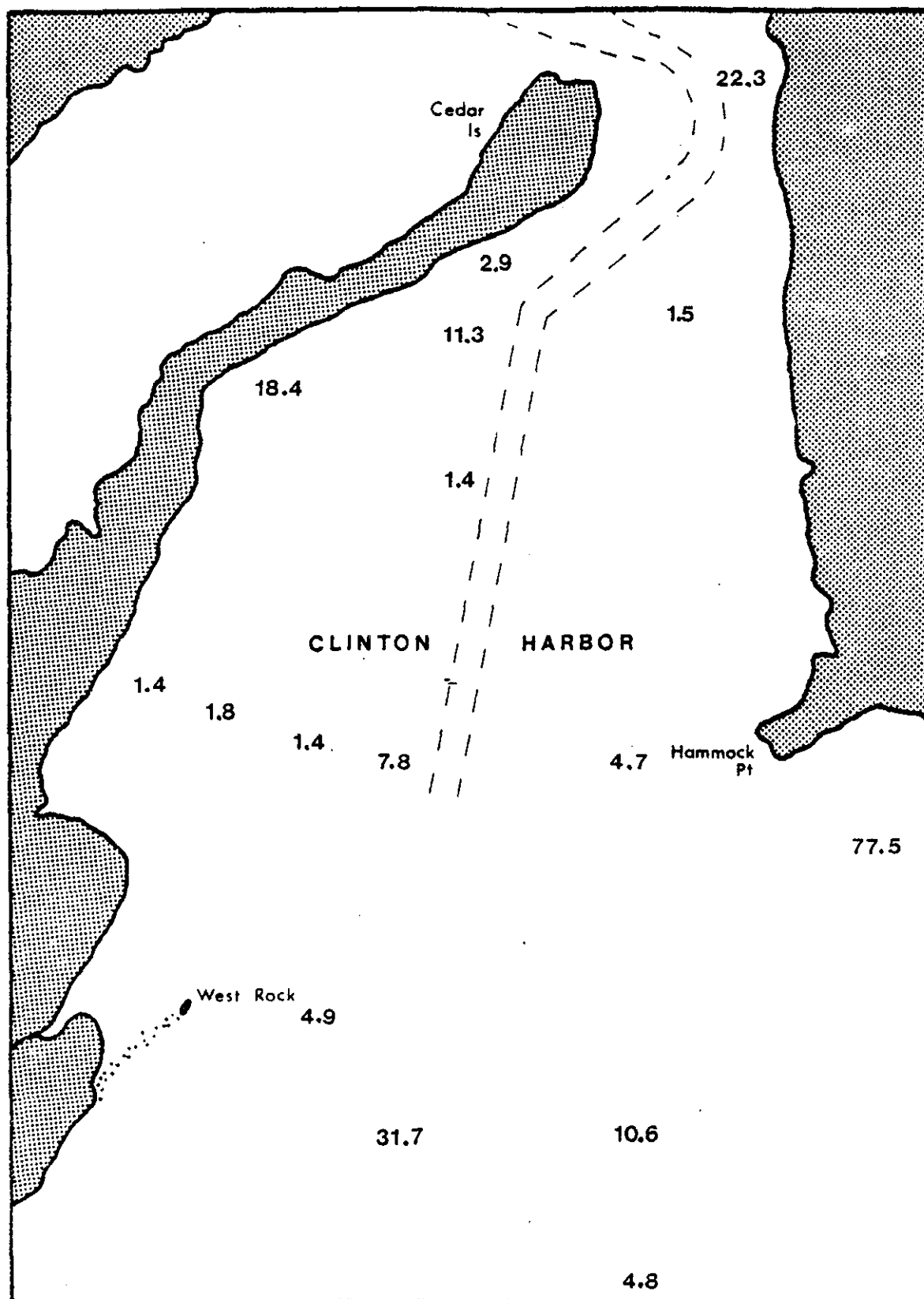
Figure 15. Sediment percent silt-clay, October sampling.

The overall effect of the changes in sediment type between September and October was to reduce differences in sediment between the various stations in the study area. This produced species lists with considerably more overlap than had been the case with the September data.

2.3   Discussion and Conclusions

Two previous studies have been conducted on benthic macrofauna in the Clinton Harbor area. The first of these (Pellegrino and Baker, 1975) was concentrated in the inner harbor and in the vicinity of our Station 14. The results of that work, therefore, have limited application in the investigation of conditions in the outer harbor. In addition, Pellegrino and Baker used a 1.0mm sieve and it is not possible to compare their data with ours which were developed with a 0.5mm sieve.

Some of the difficulties involved in comparing the Pellegrino and Baker study with the present data may be seen in the differences between some of the summary parameters. For example, Pellegrino and Baker identified a total of 30 species of invertebrates while we found 145. This discrepancy is due to the sieve size difference noted above, the variety of habitats sampled and, we believe, the level of taxonomic expertise. In some cases, particularly in the October samples, we identified more than 30 species at a single station.

As would be expected from the difference in sieve size, our data indicate a much higher faunal density than that reported by Pellegrino and Baker. They reported a mean number of individuals per m^2 of 293.4 while for the present study this parameter was 4,833 for the September sampling and 13,165 for the October sampling.

A previous study of Clinton Harbor using techniques identical with those in the present survey and incorporating stations in the outer harbor was conducted by Taxon, Inc., in 1977 (McGrath, et al., 1978). That study included two stations within the proposed disposal area, two stations in the vicinity of the present Stations 6 and 12, respectively, and one station at the site of the present Station 14. In addition, sampling was conducted at the same time of year.

McGrath, et al., reported a total of 68 species from the 1977 survey, far short of the 145 species collected in the present study. Some of this difference may be attributed to the greater intensity of sampling in 1981 and to the placement of stations in habitat types that were not sampled in 1977. Comparison between the two surveys was much closer for faunal density with overall mean densities of $6,748/m^2$ in October and $6,094/m^2$ in November vs. the $4,833/m^2$ (September) and $13,165/m^2$ (October) in the present survey.

The dominant species in the harbor in 1977 were identified as *Streblospio benedicti*, Oligochaeta, *Tharyx acutus*, *Scoloplos fragilis*, *Tellina agilis*, *Eusyllis* sp. and *Ilyanassa obsoleta*. All these species were again common in the present study, except that the *Scoloplos* in the present study was identified as *S. acutus* rather than *S. fragilis*. We do not know if this is due to misidentification of specimens from the earlier study or is a real change from one species to another within this genus, although the former explanation appears more likely based on the overall similarity between results from the two studies.

The only major discrepancy between the macrofaunal communities described from 1977 and those reported from the present study involves the distribution of the common polychaete *Streblospio benedecti*. In 1977, three community types were described, two of which were based on the presence or absence of this species. The area of the proposed disposal project was described as being characterized by low densities or total absence of *Streblospio*. For the 1981 data, *Streblospio* is one of the characteristic species found in this habitat. Without additional data from the period between the two samplings, it is impossible to speculate on the reasons for this apparently anomalous change in the distribution of *Streblospio* but it does not change any of the conclusions in regard to the ecological value of the proposed disposal area.

The benthic macrofauna in a number of other Connecticut harbors have been the subject of extensive investigations in recent years. Most recently, Taxon, Inc., participated in a study of the benthos of Bridgeport Harbor and Black Rock Harbor (McGrath, 1981) and New Haven Harbor has been studied in conjunction with the operation of a steam-electric generating station (Hartzband, et al., 1979). These harbors differ from Clinton primarily in the amount of anthropogenic impact they receive and the subsequent environmental degradation provides a useful index against which the conditions in Clinton may be evaluated.

Black Rock Harbor is characterized by an inner harbor area of heavily contaminated silt-clay substratum and an outer harbor of poorly-sorted mud, shell and sand (McGrath, 1981). Faunal communities in the inner harbor are, when present, dominated by the classic opportunist polychaete *Capitella capitata*. This type of situation was never found at Clinton and this level of degradation is clearly absent from the Clinton Harbor system. *Capitella* does occur in the harbor, but never as a dominant. This may not be strictly correct in some areas of the inner harbor for the warmest periods of the year, but even then it would be a normal situation rather than one caused by human activity.

Outer Black Rock Harbor generally supported communities which had greater species richness and faunal density than outer harbor stations at Clinton. This may be due to two factors, sediment type and season. Outer Black Rock Harbor has a shelly sandy mud bottom which can be extremely productive due to the variety of micro-habitats it affords. This type of substratum is generally not found in the outer harbor at Clinton. Also, the Black Rock survey was done in April and August and may not be strictly comparable with the September and October data from Clinton.

A similar situation to that described above for Black Rock Harbor was also found to exist in Bridgeport Harbor (McGrath, 1981). Azoic or impoverished communities inhabiting inner harbor muds grade into very rich and diverse communities in the coarser sediments of the outer harbor. As at Black Rock Harbor, these outer harbor communities were found to be more diverse and dense than those at Clinton.

New Haven Harbor, which has been studied far more extensively than any other harbor on Long Island Sound, appears to be considerably more severely impacted than both Bridgeport Harbor and Black Rock Harbor. In a summary of over five years of data, Hartzband, et al. (1979) reported species richness and faunal density in most areas of both inner and outer New Haven Harbor at values well below those from Bridgeport, Black Rock, and Clinton.

This pattern of community parameters indicates that Clinton Harbor appears to be a relatively unimpacted and well-balanced estuarine ecosystem. No evidence was found to indicate changes in natural communities due to human activity and there was generally very little evidence of stress due to natural conditions. The comparatively low richness and density at some outer harbor stations is evidently related to natural conditions such as sediment type or exposure.

In the proposed disposal area at Clinton Harbor, the resident faunal community appears to be normal, well-balanced, and typical of many northeast estuaries with similar sedimentary and hydrographic regimes. Species such as Tellina agilis and Streblospio benedicti, the most characteristic species at Clinton, are reported from many areas and form the basis of what may be considered the normal muddy-sand community.

As may be seen from the finfish section of this report, these benthic inverte-brates are a valuable food source for the bottom-feeding fishes, primarily winter flounder. Although these and similar invertebrate species are found in many other areas, the removal of this area from the Clinton Harbor system will unquestionably result in a decrease in available food for the resident bottom-feeding fishes. It is

important to note in this regard that the boundaries of the proposed disposal area coincide with the boundaries of this particular community and thus, filling of this area would delete one entire habitat type from the harbor. There is, however, nothing to indicate that this area is unique in the sense that the habitat type or any of the resident species are found nowhere else. As noted previously, the area is a common habitat-type inhabited by common species.

3.0 SHELLFISH

3.1 Methods

Shellfish samples were collected from the proposed container disposal area in outer Clinton Harbor on 19 and 20 August 1981. All sampling was done within approximately one hour before and after low water, at which time there was approximately 0.5m of water over most of the study area.

Samples were taken by driving a large (0.25m^2 area) metal cylinder into the substratum and removing the underlying water by bucket. This made it possible to remove bottom sediment from the cylinder to a depth of approximately one foot. All sediment was passed through a 0.25 inch mesh sieve as it was excavated. Four such samples were taken per station to provide a total area sampled of 1.0m^2 at each station. Five stations, shown in Figure 16, were sampled.

In addition to the quantitative samples described above, a qualitative survey was made of the intertidal zone in the vicinity of Hammonasset State Park. This comprised a visual survey of a localized oyster (Crassostrea virginica) population which was noted during the collection of beach seines, and some attempts to locate a softshell clam (Mya arenaria) population which had been reported from the area. This survey was confined to the area indicated in Figure 16; conditions in the intertidal zone further north along the shoreline (clean sand beaches and "peat" deposits) were judged to be incapable of supporting significant populations of edible shellfish.

3.2 Results and Discussion

No shellfish were found in any of the subtidal shellfish samples. We believe that some hard clam (Mercenaria mercenaria) and bay scallop (Aequipecten irradians) populations exist in this area but they are either too localized or too sparse to be of possible commercial importance. They may have some value as a recreational resource based upon the results of an informal interview we conducted with one individual who was observed clamming in the area. He indicated that clamming (for Mercenaria) was "good" throughout the shallower zone in the disposal area and that he fished the area frequently. When asked for some more quantitative measure of his catch per unit effort he estimated a catch of 4-5 adult quahogs per tide or about one clam per hour. A rate of one clam pe hour for an apparently experienced recreational clammer would probably not be considered good in many areas.

Based upon the results of our quantitative survey and the information described above, the proposed disposal area does not appear to support subtidal shellfish

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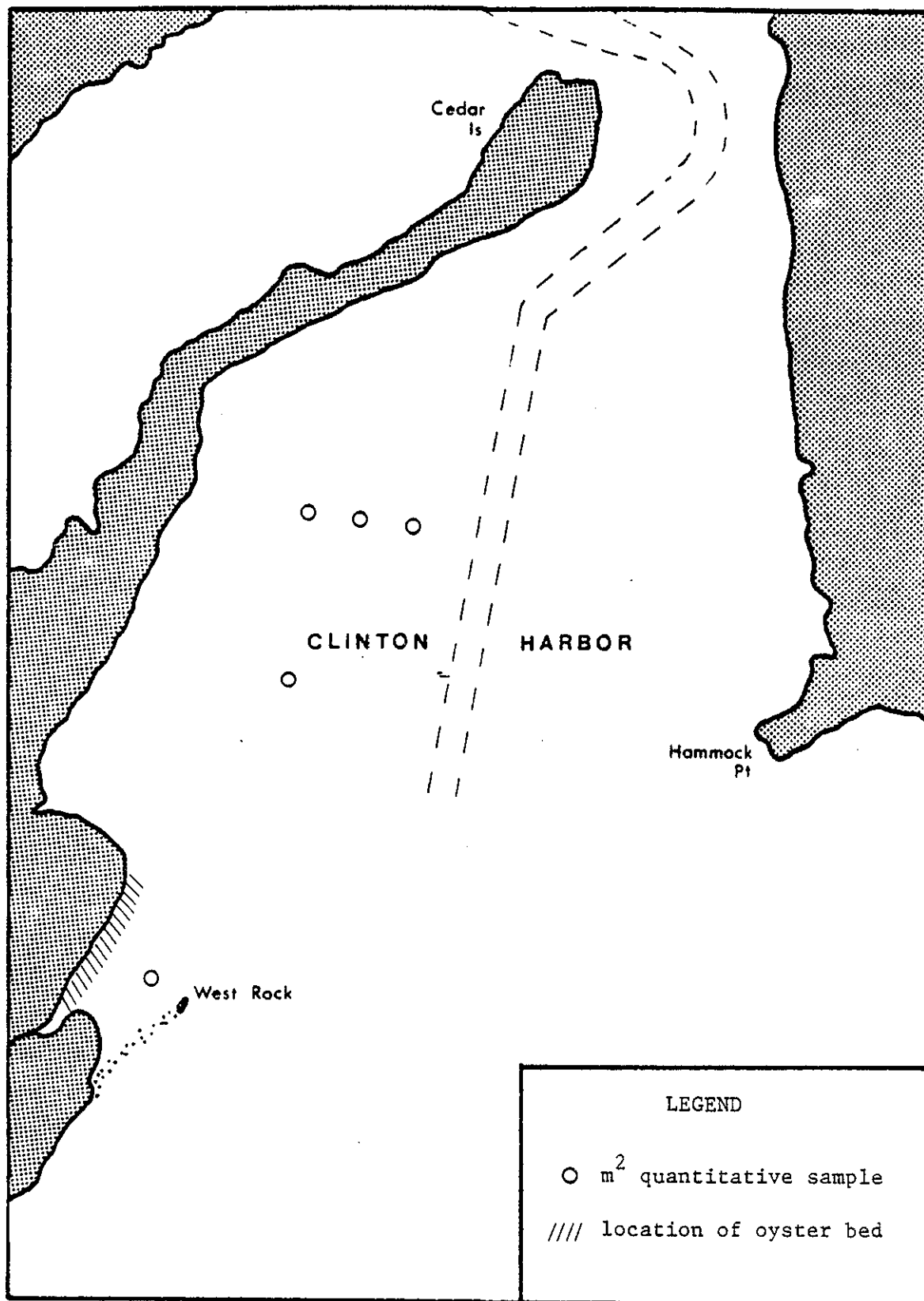
Figure 16. Shellfish sampling sites.

populations in exploitable densities. In the intertidal area just north of the small tidal creek draining Hammonasset State Park (see Figure 16) we located a small but moderately dense population of oysters (Crossostrea). These were distributed over a mud/shell/gravel bottom extending a few hundred meters north of the creek mouth. Although the density of this population appeared sufficient to support at least recreational harvesting, the small amount of suitable substratum in the area limits the overall value of this resource.

Finally, the clammer discussed above mentioned the presence of a population of soft-shell clams (Mya) in the area of oyster population. In order to investigate this possibility, we sampled a series of approximately $1m^2$ quadrats along the shoreline, at various tidal elevations. After excavating several square meters in this manner, we had collected only two adult Mya. Based upon these results, the area does not appear to support harvestable populations of this species.

In summary, four species of commercially valuable molluscs are known to inhabit the proposed disposal area: hard clams, or quahogs (Mercenaria mercenaria), bay scallops (Aequipecten irradians), American oyster (Crassostrea virginica) and the soft-shell clam (Mya arenaria). None of these, however, appears to support a commercial, or anything beyond a very casual recreational, fishery.

4.0 FINFISH

4.1 Methods

Finfish collections were conducted on August 18 and 19 at the six beach seine (S1-S6) and six trawl stations (T1-T6) shown in Figure 17. Due to the extremely soft substratum in the inner harbor, it was not possible to use a beach seine on the inside of Cedar Island. As an alternative, a sampling station was located at the tip of the island where the substratum consisted of hard sand.

Two different sampling methods were employed to collect finfish from Clinton Harbor. A beach seine was used to collect fishes from the edge of the shoreline out to a depth of 2m. Sampling in areas deeper than 2m was conducted using an otter trawl.

Beach seine collections were made using a 17m x 2m seine with a one-quarter inch mesh. The seine was deployed perpendicular to the shoreline and walked approximately 150 feet parallel to the beach at each station, after which it was pivoted and pulled ashore. Specimens were removed from the net, placed in muslin bags, and immediately fixed in a 10% formalin solution.

Trawl collections were conducted using an otter trawl of 15 feet width and one inch mesh with a one-quarter inch mesh cod end liner. At each station the net was towed approximately 15 minutes at a speed of two knots for a total tow of approximately 0.5 nautical miles. Fishes collected were handled similarly to the beach seine samples. Specimens larger than 3cm in length were opened along the body cavity to allow proper preservation of body tissue and gut contents.

Upon return to the laboratory, all specimens were transferred to a 70% isopropanol solution. Specimens were then identified, enumerated, measured to 0.1mm, and weighed to 0.01g. Summer flounder, windowpane and weakfish were measured to the caudal peduncle (standard length); silverside, bluefish and anchovy were measured to fork length. All remaining species were measured to total length. Aging and gut content analysis was conducted on all specimens of the dominant species except for silversides for whom a representative subsample of the entire captured population was used. Dominant species are defined as those species occurring in at least half of the trawl stations or half of the beach seine stations, respectively.

Scale samples were removed from the dominant species at a point immediately below the front edge of the dorsal fin and above the lateral line on the left side. Permanent dry mounts were made of all scale samples. Age was determined by projecting the scales on an Eberbach scale reading machine to 42x and counting annuli outward from the scale focus. Age was defined as the number of growing seasons (as

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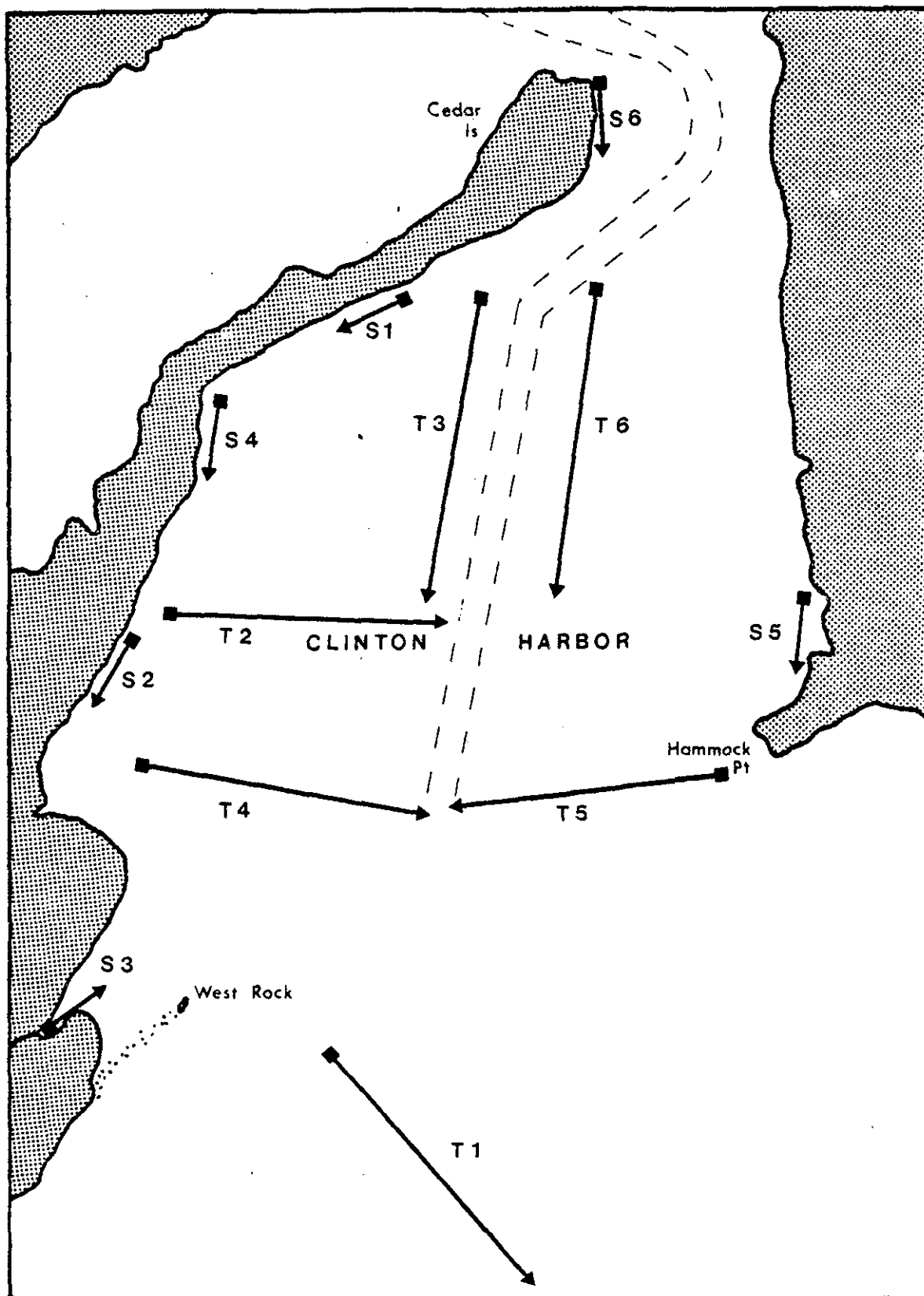
Figure 17. Location of finfish otter trawls (T1-T6) and beach seines (S1-S6).

45

marked by the presence of an annulus) that a fish had completed. Thus, 0+ aged fish was less than one year old (young of the year), while a I+ aged fish was at least one, but less than two years old. Length/frequency was plotted for the dominant species.

Stomachs were removed from the dominant species for gut content analysis. The stomachs were opened and the contents of each were washed into a petri dish for examination under a stereomicroscope. Contents were identified to species level or as far as possible based on condition, and enumerated. Frequency of occurrence and percent composition were computed for the various food items.

4.2 Results and Discussion

4.2.1 Community Composition

Fifteen different species were captured at the trawl stations. Catch results are displayed in Table 8. Keeping in mind the bias inherent in any finfish sampling technique (gear selectivity, net avoidance capabilities of different species, etc.) as well as the time of the year sampling took place, the dominant species were found to be summer flounder (Paralicthys dentatus) and winter flounder (Pseudopleuronectes americanus). Though relatively few numbers of summer flounder were taken, their presence at four of the trawl stations establishes them as a dominant species in the Clinton Harbor area. The overall low numbers caught were probably due to the fact that summer flounder are strong and active swimmers and could easily avoid a trawl of small size fished at a relatively slow speed.

Five species comprised the nearshore fish community at the six seine stations. Silversides (Menidia menidia) were the dominant species. Mummichogs (Fundulus heteroclitus) were not considered to be dominants due to their presence at only one of the seine stations.

4.2.2 Age Structure of Dominant Species

Younger fish predominate in the population of summer flounder sampled. Of the seven specimens of summer flounder caught, 14.3% were in the 0+ age group, 71.4% were in the I+ age group and 14.3% were in II+ age category. Because of the small number of specimens it is difficult to draw generalizations about the population in the harbor. However, the age structure of the specimens captured is probably representative, in that younger fish comprise the bulk of the population, older fish being found further offshore.

TABLE 8
CAPTURE RESULTS FOR CLINTON HARBOR

Station	T1	T2	T3	T4	T5	T6	S1	S2	S3	S4	S5	S6
SPECIES:												
Summer Flounder	2	3	1		1							
Winter Flounder		4	7	2	3	11						
Toadfish						1						
Silverside		1		2			383	254	29	16	125	50
Mummichog									71			
Killifish						1			2			
Bluefish								3				2
Tomcod						1			1			
American Eel				1		2						
Pipefish					2	1						
Puffer				1								
Windowpane	13				2							
Anchovy	19											
Weakfish	37											
Longhorn Sculpin	3				3							
Little Sculpin					1	3						
Tautog						1	1					
Rockeel					1							

47

As with summer flounder, younger fish make up the largest segment of the population of winter flounder found in Clinton Harbor. As may be seen from Figure 18, I+ and II+ aged fish were most common. Of the total 28 specimens captured, one was O+, 11 were I+, and 13 were II+. In addition, one III+ and one IV+ fish were caught.

Silversides were the most abundant species taken in the harbor, being present in virtually all the seine samples, often to the exclusion of other species. Given the schooling nature of the species, the large number caught at each station is to be expected. This species is relatively short-lived reaching a maximum age of about two years. The bulk of the specimens captured in the seine fell into the one to two year old age class (Figure 19). Fewer O+ (young of the year) fish were taken, most likely due to the mesh size of the seine.

4.2.3 Gut Content Analysis

Listings by species of all food items found in specimens examined are contained in Tables 9, 10 and 11.

A wide variety of food items was identified in the stomach contents of the dominant fish species. Demersal, as opposed to pelagic, feeders contained the greater variety of food items.

Several factors impinge upon the problem of determining the diet of a particular fish species. The most important of these is differential digestion rates, which lead to the selective accumulation of food items that are processed more slowly. Other food items may be absent entirely from the gut contents depending on how soon prior to capture the fish had eaten and, again, how rapidly certain food items were digested.

The sand shrimp (Crangon septemspinosa) was the dominant food source both in frequency of occurrence and percent composition, of the summer flounder (Table 11). The lady crab (Ovalipes ocellatus) was present in over 33% of the stomachs examined and probably constitutes a major dietary item. Evidence of cannibalism was indicated by the presence of juvenile Paralichthys. Because of the small number of stomachs examined, caution must be exercised in applying the apparent dietary habits of those specimens of summer flounder examined to that of the population in Clinton Harbor.

Twenty-two different types of food items were found in the 26 winter flounder stomachs examined (Table 9). Polychaetes predominated, being found in 61.5% of the stomachs. Among polychaetes, species of the family Spionidae were present in the greatest numbers. Given the relative abundance of worms of this family in the harbor, this is to be expected. Glycerid worms were another frequently encountered family,
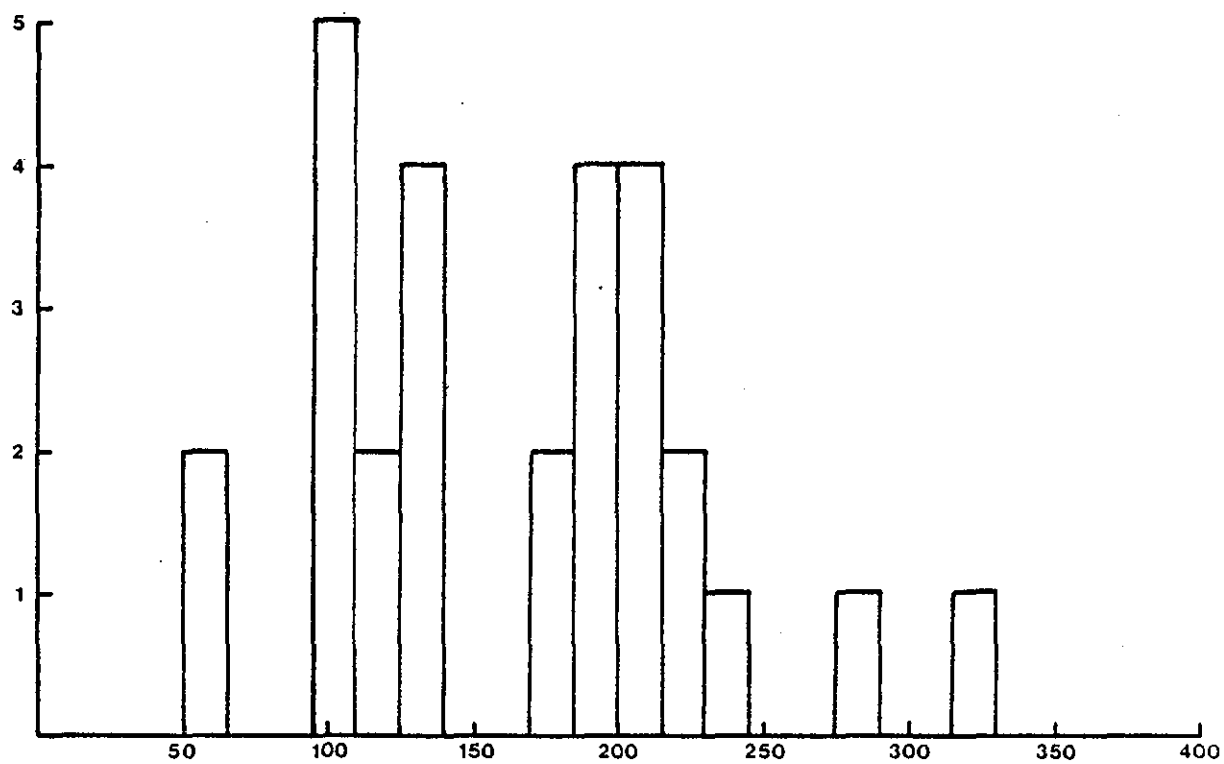
Figure 18.   Length-frequency histogram for winter flounder (Pseudopleuronectes
              americanus).
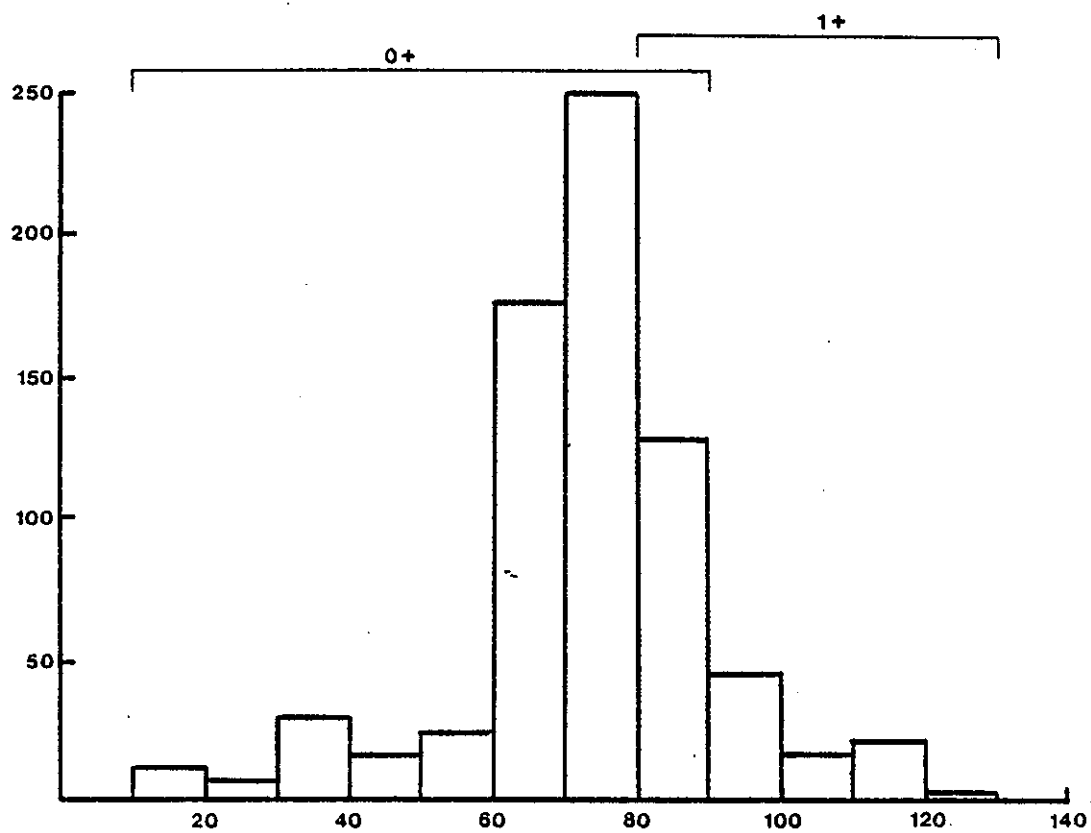
Figure 19.   Length-frequency histogram for silversides (<u>Menidia</u> <u>menidia</u>).

TABLE 9

GUT CONTENT ANALYSIS DATA FOR Pseudopleuronectes americanus

Food Item	Frequency of Occurrence (%)	Percent Composition by Number (%)
Glycera americana	23.1	6.0
Mediomastus sp.	7.7	3.0
Nephtys sp.	3.8	1.0
Spionidae	3.8	11.0
Streblospio benedicti	3.8	8.0
Phyllodocidae	7.7	3.0
Nereidae	3.8	1.0
Capitella capitata	3.8	1.0
Pectinaria gouldii	3.8	1.0
Clymenella torquata	7.7	3.0
*Polychaetes (total)		31.0
Tellina agilis	11.5	5.0
Ensis directus	38.5	28.0
Macoma tenta	7.7	2.0
*Bivalves (total)		45.0
Corophium sp.	3.8	1.0
Ampithoe valida	3.8	1.0
Listriella barnardi	7.7	2.0
Ampelisca abdita	3.8	1.0
*Amphipoda (total)		7.0
Pagurus sp.	3.8	1.0
Ovalipes ocellatus	7.7	2.0
*Brachyurans (total)		3.0
Homarus americanus	3.8	1.0
Crangon septemspinosa	11.5	4.0
Heteronemertea	3.8	1.0

*Whole identifiable specimens (does not include fragments)

TABLE 10

GUT CONTENT ANALYSIS DATA FOR Menidia menidia

Food Item	Frequency of Occurrence (%)	Percent Composition by Number (%)
Balanus sp.	2.7	less than 0.1
Ostracoda sp.	17.9	1.7
*Crangon septemspinosa	30.8	less than 0.1
*Copepoda	74.4	82.8
larval crustaceans	20.5	0.2

*Whole identifiable specimens (does not include fragments)

TABLE 11

GUT CONTENT ANALYSIS DATA FOR Paralichthys dentatus

Food Item	Frequency of Occurrence (%)	Percent Composition by Number (%)
Crangon septemspinosa	85.7	94.5
Ovalipes ocellatus	28.6	3.9
Paralichthyidae	28.6	1.6

being found in over 23% of the stomachs examined, indicating that winter flounder are also utilizing this abundant group.

In addition to polychaetes, bivalves were also a major dietary constituent of winter flounder, being found in over 57% of the stomachs examined. The most frequently encountered bivalve was the razor clam (Ensis directus). Tellina agilis occurred in relatively low numbers (11.5%) in comparison with the razor clam. Given the relative abundance of Tellina, it appears that winter flounder selectively feed on Ensis in preference to Tellina. The sand shrimp was the most commonly found crustacean although in terms of total numbers found, its value was relatively small.

Results of the gut content analysis of silversides (Menidia menidia) are shown in Table 10. Pelagic copepods dominated in the diet of specimens examined both in terms of frequency of occurrence (74.4%) and percent composition (82.8%). These results indicate that copepods are the principal food source for silversides; numerical percentages of other food items were negligible. In comparing copepods and sand shrimp as food items, frequency of occurrence is a more useful figure due to the size difference between the two. Sand shrimp were found in 30% of the stomachs examined; these stomachs were from the larger specimens and it appears that only the larger silversides use sand shrimp as a food item. Ostracods and larval crustaceans (principally decopod zoea) were present in 17.9% and 20.5%, respectively, of the stomachs examined, although both constituted a negligible quantity in comparison to copepods. From the evidence provided by stomach contents it appears that silversides do most of their feeding in the water column rather than on the bottom.

5.0 INTERTIDAL ALGAL POPULATIONS

5.1 Methods

Intertidal algal collections and observations were made on August 18 and 19, 1981. The purposes of the survey were to document the varieties of algae in the outer Clinton Harbor area and to describe the nature and extent of the resident algal communities.

The area surveyed was restricted to the western shore of the outer harbor, along a one-mile stretch of coastline between the entrance to the inner harbor at Cedar Island and the eastern boundary of Hammonasset State Park. The survey was conducted entirely on foot, and all segments and tidal levels of the investigated shoreline were visited at least once during each phase of the tidal cycle.

Both quantitative and qualitative field sampling techniques were employed to describe the algal communities in the survey area. The primary quantitative sampling technique involved the use of a 3cm transparent plexiglass overlay on which were twenty-five random dots. The overlay was placed directly on a segment of the algal community and the species occurring beneath each dot were recorded. Five replicates were obtained for each community investigated. The resultant data permitted an enumeration of the dominant macrofloral species within each community, and provided an accurate measure of the percent cover of each.

Supplementary quantitative sampling was performed to identify those algal components of each community which were of insufficient size or abundance to be quantitatively measured. This group of plants comprised primarily the smaller epiphytic species, but also included juvenile and diminutive forms of several macroscopic species. Qualitative sampling was accomplished by a thorough examination of the entire algal population within each quantitative quadrat. Species encountered solely from the qualitative phase of the survey were recorded as occurring in "trace" amounts.

Representative specimens of all species were preserved in a 5% formalin solution and transferred to the laboratory. Taxonomic verification of all specimens was performed using both a compound and stereomicroscope. Taxonomic identifications were based upon the works of Taylor (1957), Parke and Dixon (1976), and South (1976). Voucher specimens of all taxa encountered during the survey have been prepared and are currently stored at Taxon, Inc.

54

5.2 Results and Discussion

Most of the outer Clinton Harbor intertidal zone was of a moderate to high relief, and consisted primarily of lengthy unbroken stretches of medium to coarse-grained sand interspersed with small aggregates of fist-sized cobble. An estimated 60% of the intertidal substratum was of the mixed sand and cobble type. A sand/cobble matrix is not a favorable habitat for algal germination and growth, and no colonization of this substratum was observed in the outer harbor area.

Soft mud accounted for an additional 30-35% of the outer harbor intertidal substratum. The mud occurred primarily in variously-sized patches within the more widespread sand/cobble substratum. Mud substratum was particularly expansive at the mid and low intertidal zones, and was considerably more common near Hammonasset State Park where localized erosion of the boundary of the existing marsh contributes to the formation of this substratum. Soft mud represents an equally unsuitable habitat for intertidal algal development, and no macroalgal colonization of mud surfaces was observed.

Intertidal habitat suitable for algal colonization was found in only 5% of the survey areas. Three different habitat-types were identified, each supporting its own distinct algal community. These have been termed the rock substratum algal community, the salt panne algal community, and the tidal creek algal community (Figure 20).

5.2.1 The Rock Substratum Algal Community

A complete list of species found in the rock substratum algal community is presented in Table 12. The occurrence of rocky intertidal substratum was restricted to a small area bordering on Hammonasset State Park at the far western periphery of the outer harbor region. The area consisted of a large, seaward-facing, rocky outcrop together with a lengthy rock dike. The dike served to separate the outer harbor from Long Island Sound.

The rocky outcrop consisted of continuous rock substratum from the high to the low intertidal zones, continuing out into the subtidal region. The high and mid zones were of extremely high relief and consisted of rounded, well-weathered boulders of moderate to large size. The low intertidal and shallow subtidal zones were of a more gradual relief, and comprised smaller boulders together with rocks and cobble of various sizes.

The south-facing outer side of the rock dike was of moderately high relief at all intertidal elevations and was composed primarily of medium sized boulders
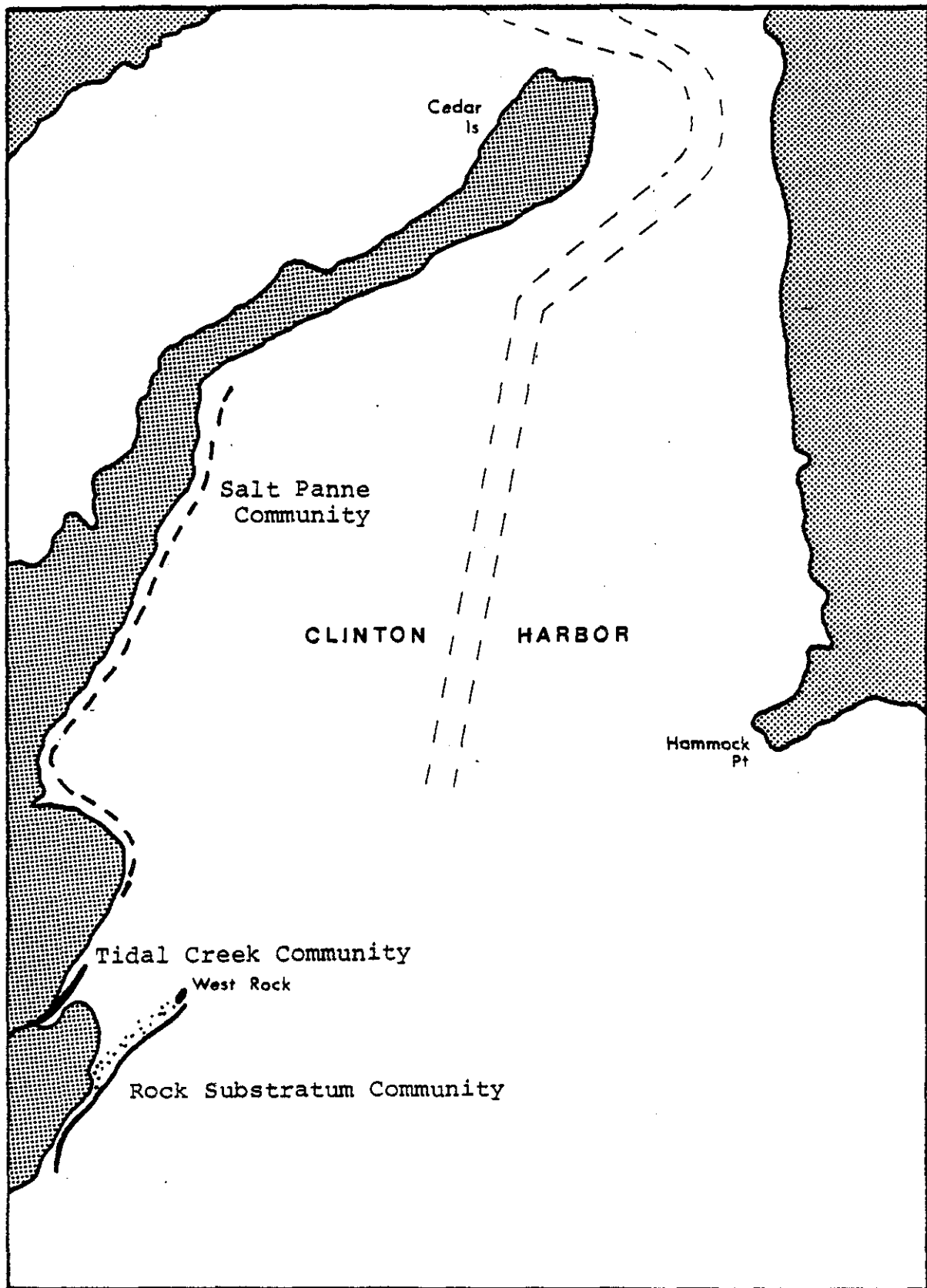
Figure 20. Sampling areas for algal survey.

TABLE 12

PERCENT COVER OF ALGAL SPECIES COLONIZING THE ROCKY INTERTIDAL SUBSTRATUM OF OUTER CLINTON HARBOR

	Replicate				
	1	2	3	4	5
Chlorophyta (Green Algae)					
Blidingia minima	T		T		
Chaetomorpha linum	4	T	4	4	T
C. melagonium		4	T		T
Cladophora albida		T	T	4	4
C. sericea	T			T	
Enteromorpha clathrata	T				T
E. flexuosa		T			
E. intestinalis			T	T	
E. linza			T		
E. prolifera				T	
Rhizoclonium riparium	T		T		T
Ulva lactuca	4	T	4		T
Phaeophyta (Brown Algae)					
Ascophyllum nodosum	8	T	8	16	
Ectocarpus siliculosus	T			T	T
Elachista fucicola	T			T	T
Pilayella littoralis	T				T
Ralfsia verrucosa	T	T	T	T	
Rhodophyta (Red Algae)					
Ahnfeltia plicata		T	4		4
Antithamnion americanum					T
Ceramium rubrum	T	T	T	T	T
Chondria tenuissima	T				
Chondrus crispus	68	76	56	52	76
Corallina officinalis	4			8	T
Cystoclonium purpureum	T	T		T	
Gigartina stellata	4	T	16		8
Goniotrichum alsidii	T	T			

TABLE 12 - Continued

	Replicate				
	1	2	3	4	5
Rhodophyta (Red Algae)(cont.)					
Gracilaria foliifera	4		4	T	
Palmaria palmata		4			
Polysiphonia denudata	T	T		T	
P. harveyi	T	T	T	T	T
P. lanosa	T		T	T	
P. urceolata		T	T		T
Porphyra leucosticta		T		T	
Total Algal Cover (%)	96	84	96	84	92
Total Species Number	22	18	18	17	17

Legend: T = present in trace amounts only.

and large rocks. The inward- facing side of the dike was of a moderately high relief at the high and intertidal levels, but of a much more gradual relief at the low intertidal and shallow subtidal levels. Medium sized boulders and large rocks were the predominant substratum at the high and mid tidal levels. The low intertidal and shallow subtidal regions comprised hard mud and sand interrupted by the protruding surfaces of buried rocks and boulders.

The high and mid intertidal regions of both the rocky outcrop and the rock dike were only sparsely and irregularly colonized with intertidal algae. Approximately 75% of the rocks and boulders were completely devoid of algal growth. Representatives of only five green algal species were encountered: Ulothrix flacca, Blidingia minima, Enteromorpha linza, E. prolifera, and Ulva lactuca. Quantitative sampling techniques were not utilized because of this lack of algal cover. However, a qualitative examination of a representative sample indicated that Blindingia minima and Enteromorpha linza were the more common of the five species. Individuals of all species were small in stature, with most being no more than 2-4cm in length. The diminished level of algal colonization in the higher intertidal zones is believed to be due to the increased exposure associated with high relief habitats. Many plants observed evidenced the frayed apices indicative of high exposure conditions.

The low intertidal and shallow subtidal regions of the inner side of the rock dike also had minimum algal cover. The sand and mud, which constituted the greater portion of the substratum, supported no algal growth and algal colonization was restricted to the surfaces of the small number of protruding rocks and boulders. Only four very sparsely distributed species were encountered: the macrophytic red algae Chondrus crispus and Gigartina stellata, and the smaller green algae Ulva lactuca and Enteromorpha intestinales. The reduced level of algal colonization was due to the sand and mud substratum, as algal germination is known to be inhibited by the presence of either. Sand and mud also continuously abrade the holdfasts of juvenile and mature individuals, thereby increasing the susceptibility of the plants to dislodgement from the substratum.

The lower intertidal and shallow subtidal regions of both the rocky outcrop and the outer face of the rock dike were characterized by moderately high species richness and very extensive algal cover. A combined total of 33 species was recorded for the five replicates sampled. These consisted of 12 members of the Chlorophyta (green algae), 5 members of the Phaeophyta (brown algae), and 16 members of the Rhodophyta (red algae). Species richness was similarly high within the individual

replicates; the number of species collected from the five replicates ranged from 17 to 22. The percentage of algal cover was also very high. For each of the five replicates, the algal community covered between 84% and 96% of the available substratum.

The low intertidal and shallow subtidal regions were dominated by the macroscopic carrageenoid red algae Chondrus crispus. Chondrus was recorded from each of the five replicates sampled. In addition, the percent cover of Chondrus in each replicate was extremely high, ranging from 56-76%. The major subdominant species were the macroscopic red alga Gigartina stellata and the macroscopic brown alga Ascophyllum nodosum. Both species were encountered in four of the five replicates, and had a maximum cover of 16%. Additional benthic species which were well represented were the green algae Chaetomorpha linum and Ulva lactuca, and the red algae Ahnfeltia plicata and Corallina officinalis. Epiphytic species also constituted an important part of the flora community. The epiphytic red algal species Polysiphonia harveyi and Ceramium rubrum were especially abundant on Chondrus. The most common epiphytes of Ascophyllum were the brown algae Ectocarpus siliculosus, Pilayella littoralis, and Elachista fucicola, together with the red alga Polysiphonia lanosa.

5.2.2 The Salt Panne Algal Community

A complete list of species found in the salt panne algal community is presented in Table 13. Salt pannes are the marsh equivalent of tide pools, and occur as shallow depressions in the surface of living or decayed salt marshes. The formation of the panne commonly occurs as a consequence of localized erosion within the marsh. Once formed, pannes serve as repositories for shells and cobble. The accumulated shells and cobbles, in turn, serve as substratum for algal colonization.

The salt pannes of the outer Clinton Harbor intertidal region are associated with a decayed marsh which presently lies buried beneath sand and cobble. Intermittent breaks in the sand/cobble cover have resulted in the exposure of sections of the underlying marsh and their associated pannes. Pannes were observed throughout the outer harbor survey area, but were found to occur in greatest numbers at the mid and low intertidal levels of the southern sections of the shoreline. The average panne was 1-2 m^2 in size and 7-10cm in depth. Approximately 20-40% of each panne consisted of potential algal substratum. The most common suitable materials were small cobbles, slipper shells (Crepidula), and surf clam shells (Spisula).

The salt panne algal community had very low species richness. A total of only eight species was recorded over the five replicates sampled. These consisted of six members of the Chlorophyta and one member each of the Phaeophyta and Rhodophyta.

TABLE 13

PERCENT COVER OF ALGAL SPECIES COLONIZING THE INTERTIDAL
SALT PANNES OF OUTER CLINTON HARBOR

	Replicate				
	1	2	3	4	5
Chlorophyta (Green Algae)					
Cladophora albida	4	T		T	T
Enteromorpha clathrata	4	T	T		˙T
E. flexusa					
E. intestinalis	8	8	4	T	˙12
E. prolifera	T	.			T
Ulva lactuca	T	T	16	8	T
Phaeophyta (Brown Algae)					
Scytosiphon lomentaria	T	4	T	T	
Rhodophyta (Red Algae)					
Goniotrichum alsidii	T		T		T
Total Algal Cover (%)	16	12	20	8	12
Total Species Number	7	5	6	4	6

Legend: T = present in trace amounts only.

Species richness was correspondingly low for the individual replicates; the number of species collected in each of the five replicates ranged from 4 to 7. Total algal cover was also relatively low, measuring from 8-20% of the available substratum for the five replicates.

The dominant members of the salt panne community, as determined by percent cover and the total number of occurrences, were the green algae Cladophora albida, Enteromorpha intestinalis, and Ulva lactuca. Each of the three was collected from all five replicates, and frequently occurred as relatively well-defined populations within each replicate.

5.2.3 The Tidal Creek Algal Community

A complete list of species found in the tidal creek algal community is presented in Table 14. A small tidal creek located in the western section of the outer harbor provided additional algal habitat. The creek originated well within the body of the marsh, and emptied into the outer harbor at a point approximately one hundred yards north of the breakwater jetty. The average depth of the creek was approximately 2', although a small number of pools were as deep as 4 to 5 feet, and a few shallow sections were only a few inches in depth. The average width was 10 feet. The creek bed consisted primarily of relatively compact sand and mud. Scattered cobble and living individuals of the oyster Crassostrea occupied an estimated 25-30% of the bed, and served as algal habitat. Approximately 80% of the cobble and oyster substratum was colonized by algae.

The tidal creek algal community was characterized by relatively low species diversity. The five replicates sampled generated a combined total of 14 species; of this number, six species were members of the Chlorophyta, and eight were members of the Rhodophyta. The number of species collected from the individual replicates ranged from eight to ten. Algal cover for each of the five replicates measured between 12-52% of the available substratum.

The macroscopic red alga Gracilaria foliifera was the dominant species, occurring in all five replicates sampled. For the five replicates, Gracilaria occupied between 12% and 24% of the available substratum. Gracilaria also appeared as the most well developed of the resident species, commonly attaining a height of 20-30cm. The green alga Ulva lactuca was the major subdominant species. Ulva occurred in all five replicates and covered up to 12% of the available substratum. Additional species which formed important components of the benthic flora were the red carrageenoid alga Chondrus crispus and the green alga Enteromorpha clathrata. The epiphytic algal population was dominated by Polysiphonia harveyi and Ceramium rubrum, with Gracilaria serving as the principal host species.

TABLE 14

PERCENT COVER OF ALGAL SPECIES COLONIZING THE
OUTER CLINTON HARBOR TIDAL CREEK

	Replicate				
	1	2	3	4	5
Chlorophyta (Green Algae)					
Bryopsis plumosa		T			
Cladophora albida				T	
Enteromorpha clathrata	T	4	T	T	8
E. flexuosa	T		T		T
E. intestinalis	T	T		T	
Ulva lactuca	T	8	T	12	8
Phaeophyta (Brown Algae)					
(No members of the Phaeophyta were encountered)					
Rhodophyta (Red Algae)					
Acrochaetium daviesii		T	T		T
Ceramium rubrum	T	T	T	T	T
Chondrus crispus	T	T	T	T	12
Gracilaria foliifera	12	12	24	20	24
Goniotrichum alsidii	T		T	T	
Polysiphonia denudata		T			
P. harveyi	T	T	T	T	T
Porphyra leucosticta			T		
Total Algal Cover (%)	12	24	24	32	52
Total Species Number	9	10	10	9	8

Legend: T = present in trace amounts only.

63

6.0 MARSH BOTANICAL SURVEY

6.1 Methods

Two areas of Hammonasset Marsh were chosen as study sites: Hammonasset State Park, located near a tidal creek close to the southwestern limit of the proposed DCMF; and Cedar Island, at the northern tip of Hammonasset Marsh, near the center of the project area. The location of these sampling sites is shown in Figure 21.

Two transects were established at the Hammonasset State Park site: one extending from the shoreline to the upper marsh, the other running parallel to the shoreline (Figure 22). Five quadrats ($1/16m^2$ each) were established by random toss along each quadrat. The plant material in each transect was clipped with hedge shears at sediment level, labelled, and individually bagged.

In the laboratory, plants were washed to remove adhering mud and each quadrat was sorted by taxa. Two species, Spartina patens and Distichlis spicata, were further separated into living and dead material litter. All sorted material was dried at $105^{\circ}C$ for 72 hours and weighed to 0.01 g. For each quadrat, live plants were enumerated by species.

At the Cedar Island site a transect was established across the peninsula from the Hammonasset River to the beach-marsh border and a visual survey made of the vegetation.

6.2 Results

Six species of marsh plants, representing four taxonomic families, were present in the collections from the Hammonasset State Park site (Table 15). The numerical densities by quadrat for these species are presented in Table 17 and biomass values are presented in Table 18.

The grasses Spartina patens and S. alterniflora were the dominant species in this community, occurring at six and seven of the ten quadrats, respectively. S. patens was restricted to the higher areas of the transect where normal tidal elevations do not reach. Live biomass of this species ranged from 38.4g to 548.0g dry weight/m^2 and litter was present in amounts ranging from 2.4g to 678.9g dry weight/m^2.

Spartina alterniflora occupied the lower supratidal quadrats on the transect, as well as the intertidal zone. Biomass values ranged from 28.6g to 295.5g dry weight/m^2; litter does not accumulate in these areas due to tidal action.

Of the two species, S. patens had higher densities, ranging from 768 to 9,376 plants/m^2 in those quadrats where it was found. S. alterniflora densities were approximately one order of magnitude lower, varying from 32 to 1,040 plants/m^2.
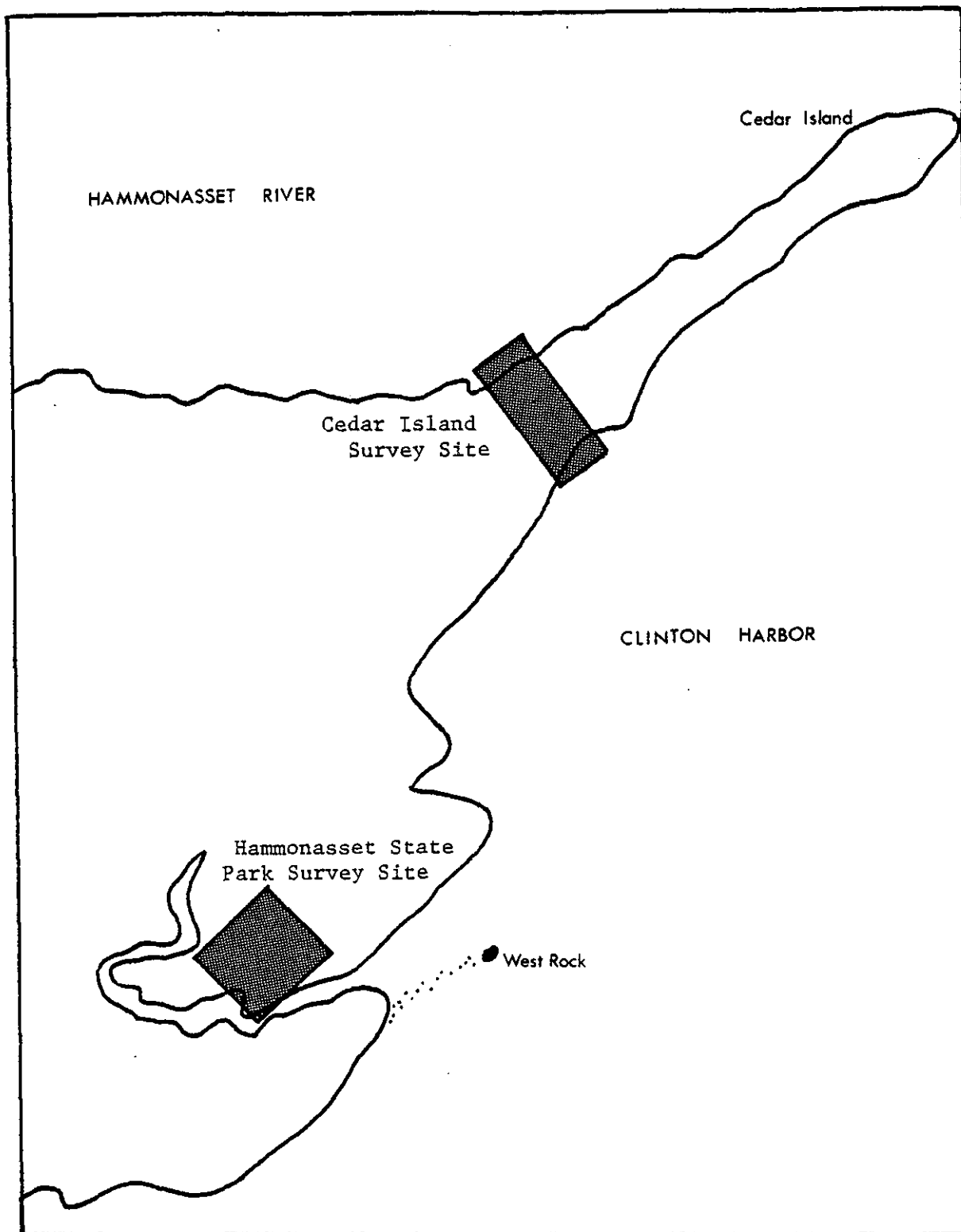
Figure 21. Locations of marsh botanical survey sites, August 1981.

65
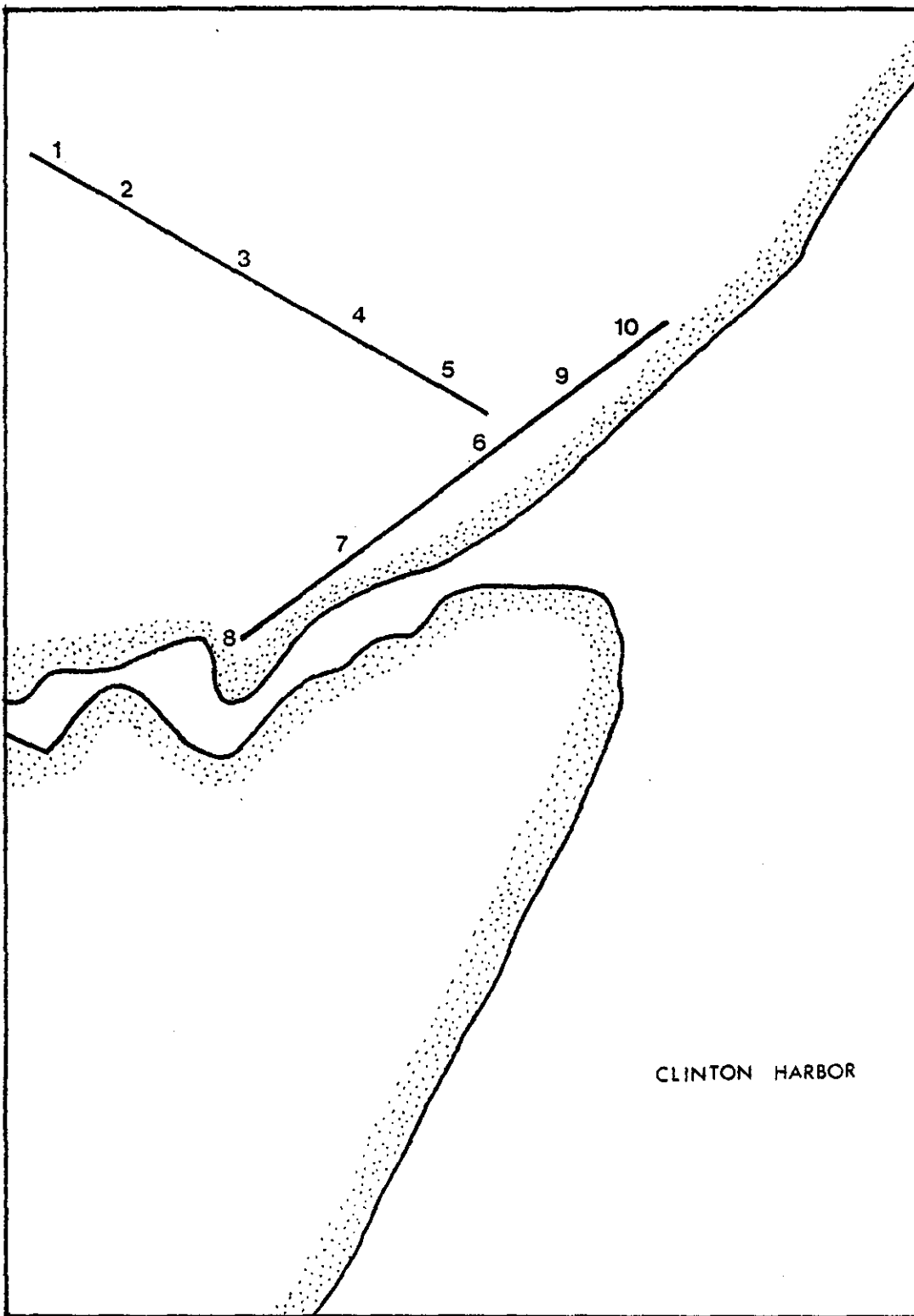
Figure 22.   Marsh botanical survey transects at Hammonasset State Park site, August
1981.

TABLE 15
SPECIES COMPOSITION OF HAMMONASSET STATE PARK SITE

Taxonomic Family	Scientific Name	Common Name
Chenopodiaceae	Salicornia europaea	Glasswort
Plumbaginaceae	Limonium carolinianum	Sea Lavender
Compositae	Iva frutescens	Marsh Elder
Gramineae	Distichlis spicata	Spike Grass
	Spartina alterniflora	Salt Marsh Cord Grass
	Spartina patens	Salt Meadow Grass

TABLE 16
SPECIES COMPOSITION OF CEDAR ISLAND SITE

Taxonomic Family	Scientific Name	Common Name
Myricaceae	Myrica pensylvanica	Bayberry
Caryophyllaceae	Spergularia marina	Sand Spurrey
Chenopodiaceae	Salicornia europaea	Glasswort
Plumbaginaceae	Limonium carolinianum	Sea Lavender
Cruciferae	Cakile edentula	Sea Rocket
Leguminosae	Lathyrus japonicus	Beach Pea
Euphorbiaceae	Euphorbia polygonifolia	Seaside Spurge
Anacardiaceae	Rhus radicans	Poison Ivy
Plantaginaceae	Plantago sp.	Seaside Plantain
Compositae	Iva frutescens	Marsh Elder
	Solidago tenuifolia	Slender-leaved Goldenrod
Juncaceae	Juncus gerardi	Black Grass
Gramineae	Ammophila breviligulata	Beach Grass
	Distichlis spicata	Spike Grass
	Phragmites communis	Common Reed
	Spartina alterniflora	Salt Marsh Cord Grass
	Spartina patens	Salt Meadow Grass

TABLE 17

DENSITY (# plants/m^2) OF MARSH VEGETATION COLLECTED AT THE HAMMONASSET STATE PARK SITE

Species	1	2	3	4	5	6	7	8	9	10
Spartina patens	9376	3040	768	3824	3280	-	2272	-	-	-
Distichlis spicata	48	256	-	-	-	-	-	-	-	-
Iva frutescens	-	-	16	-	-	-	-	-	-	-
Spartina alterniflora	-	-	-	96	32	384	48	1040	432	176
Salicornia europaea	-	-	-	-	-	-	16	32	-	-
Limonium carolinianum	-	-	-	-	-	-	16	-	-	-

TABLE 18

BIOMASS IN g DRY wt/m^2 OF MARSH VEGETATION COLLECTED AT THE HAMMONASSET STATE PARK SITE

Species		1	2	3	4	5	6	7	8	9	10
Spartina patens	living	548.0	289.8	38.4	261.4	131.4	-	174.6	-	-	-
	dead	225.1	678.9	134.1	127.8	2.4	-	99.4	-	-	-
Distichlis spicata	living	10.9	33.8	-	-	-	-	-	-	-	-
	dead	-	44.5	-	-	-	-	-	-	-	-
Iva frutescens		-	-	231.8	-	-	-	-	-	-	-
Spartina alterniflora		-	-	-	67.0	28.6	66.4	65.0	295.5	140.5	241.9
Salicornia europaea		-	-	-	-	-	-	1.3	12.2	-	-
Limonium carolinianum		-	-	-	-	-	-	175.4	-	-	-

Seventeen species representing 12 taxonomic families were identified at the Cedar Island site (Table 16). The species composition and zonation patterns of this area were typical of New England salt marshes as described by Chapman (1940) and Redfield (1972).

The area of the marsh bordering the Hammonasset River was occupied almost exclusively by Spartina alterniflora, intermixed in the intertidal area with Salicornia europaea and Limonium carolinianum. These latter two species were also found on the high marsh in water-filled depressions.

At about the high tide level, this community was replaced by an association of Spartina patens and Distichlis spicata. The upper marsh was dominated by these two grasses and a rush, Juncus gerardi, which occurred in pure stands in the drier areas. Also occurring on the high marsh were Spergularia marina, Plantago sp., Solidago tenuifolia, and Iva frutescens. Colonies of the common reed, Phragmites communis, as well as pure stands of Rhus radicans, inhabited the edge of the upper marsh. The marsh-dune interface was occupied by Myrica pensylvanica, Cakile endentun, Euphorbia polygonifolia, Lathyrus japonicus, and Ammophila breviligulata.

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SECTION V

MARSH CREATION FEASIBILITY AND DESIGN

Environmental Concern, Inc.

TABLE OF CONTENTS

Improvement dredging of the federal channel to Clinton, Connecticut, and of the private facilities in Clinton Harbor is forecasted to produce initially up to 300,000 cubic yards of dredged materials and subsequent annual quantities of about 35,000 cubic yards. Upland disposal areas for these quantities of dredged materials are not available. Environmental Concern, Inc. was requested to evaluate the shallow water area shown in Figure 1 as a possible dredged material disposal and habitat development site.

DISPOSAL AND HABITAT DEVELOPMENT SITE

1. General Conditions

Although detailed bathymetric data are not available for the site, navigation charts show water depths to average about one foot below Mean Low Water . The site faces Long Island Sound to the south-southeast and abuts the salt marsh of the Hammonasset State Park. The intertidal shore consists of pebbles and small stone surfacing finer grain sized materials. Sand moving onshore is driven by waves across the intertidal zone to a poorly vegetated sand berm that has developed above the spring tide elevation. Storm tides have irregularly flattened this berm moving sand onto the salt marsh to the northwest. An irregular band of Spartina alterniflora marsh occupies the upper half of the intertidal zone at the south end of the site. A line of large rock running from the southernmost end of the site eastward to West Rock (shown in Figure 1) renders some protection to the marsh. Because of the southerly exposure of the site, the intertidal shores and shallow bottom are subject to considerable wave stress. This stress, coupled with the coarse shore and bottom sediments, provides a poor habitat for diverse and abundant populations of benthic organisms.

A recent boardwalk has been constructed through the salt marsh of the Hammonasset State Park to the sand berm at the south end of the site (see Figure 1). This boardwalk provides public access to the site.

2. Site Suitability and Potential for Enhancement

The site is too exposed to qualify for uncontained dredged material disposal with subsequent habitat development. However, if the site is protected by a permanent breakwater constructed along its seaward perimeter, it becomes suitable for a combination of contained (for fines) and uncontained (for sands) disposal within. The breakwater could be constructed sequentially to the extent necessary to offer protection for these quantities of materials that are periodically dredged.

1
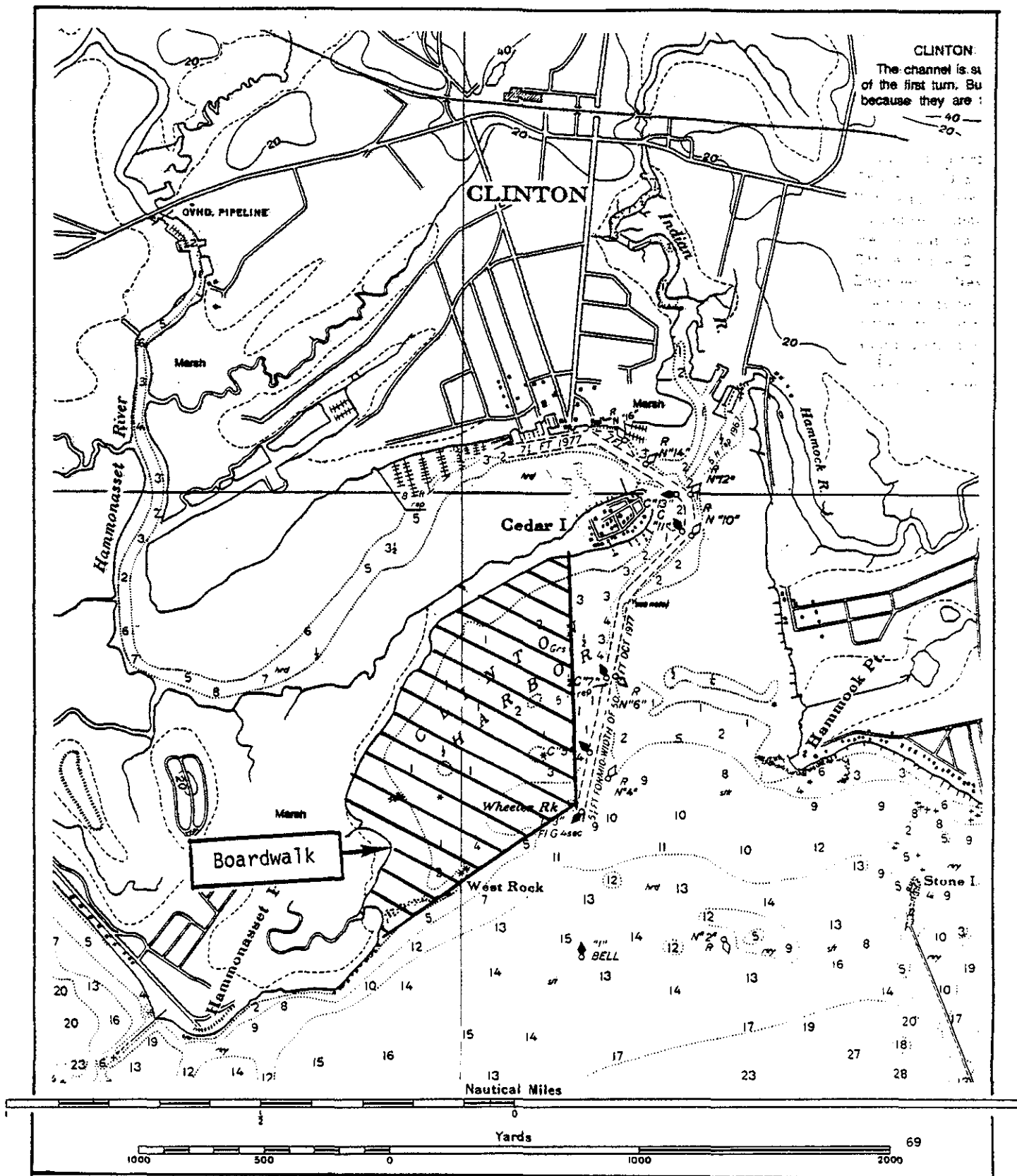
Figure 1. General location of dredged material disposal and habitat
development site.

The site has a high potential for biological enhancement. Dredged material disposal and landscaping could be designed to offer a diversity of habitat types. For example:

a. Existing intertidal shores could be retained and under the protected environment acquire a layer of finer grained sediments that would provide an improved habitat for benthos.

b. New intertidal dredged material exterior areas could be developed to provide expanded areas of mudflat-marsh edge.

c. New dredged material interior areas could be developed to provide a combination of low and high elevation salt marsh and high elevation unvegetated areas to promote tern nesting.

d. Existing shallow water areas could be retained as a refuge and feeding area for fish.

The new habitat types would have potential educational value to the local community and to visitors to Hammonasset State Park. There may be resistance from Park officials towards any dredged material development work at the site. The existing site conditions and scenery would change markedly. If the project was well presented to emphasize how it could augment and expand the Park services and functions, such resistance might be transferred to encouragement.

CONCEPTUAL DESIGN FOR DISPOSAL AND HABITAT DEVELOPMENT

1. General Conditions

Sediment samplings in the federal channel to Clinton in 1971, 1975, and 1980 show that the sediments in the Long Island Sound section of the channel generally consist of greater than 90% sand, and that the sediments in the Clinton Harbor section of the channel generally consist of greater than 90% mud (fines). Further information on the particle size distribution of the sediments and of the relative quantities of mud and sand to be initially and annually dredged are not available. Additionally, a detailed bathmetry of the site is not available. Consequently, only qualitative and conceptual considerations can be developed at this point,

In order to (1) provide protected shallow water habitat and unrestricted water circulation about any newly developed habitats, (2) provide maximum exchange potential of newly developed wetlands and the interacting tidal water, and (3) avoid restricting flow to and from the tidal creek that meanders from the site to the interior marsh of the Hammonasset State Park (see Figure 1), the dredged material disposal operation should be designed to maintain the existing conditions along the near shore and intertidal shore of the Park.

3

Recent (1980-1981) uncontained open water disposals of hydraulically dredged fine grained materials (mostly silts) by the Baltimore and Philadelphia District Corps of Engineers provided intertidal and supratidal slopes of 2000-30 to 1. With this angle of repose, fine grained materials developed to Mean High Water at the site would flow at a radial distance of 1200 to 1800 feet from the pipe outfall. In order to prevent the infringement of dredged materials on the near shore and intertidal shore of the Park, all fine grained dredged materials must be contained.

In development of a conceptual design for dredged material disposal and habitat development, the following items were assumed:

1. Mean Low Water = 0 ft; Mean High Water = 5.0 ft; Mean Tide Level = 2.5 ft; Spring Tide = 5.6 ft.

2. The average water depth throughout the site is -1 ft.

3. An adequate supply of sand to develop the containment structure for the fine grained dredged materials will be available from maintenance dredging of the Long Island Sound section of the federal channel.

4. The particle size distribution of the sand is such that hydraulic dredging and open water disposal will provide an angle of repose of about 50 to 1 of the sand deposits.

5. The stone breakwater and the sand containment structure are developed to elevations of 7 ft.

6. The fine grained dredged materials are developed to elevations between 4.0 ft to 5.0 ft.

2. Site Development

A sequential development of the site, concurrent with periodic dredged material disposal needs, is suggested. Figure 2 illustrates this sequential development. New wetland habitats would be developed throughout the sand containment structure and the fine grained materials as these areas are developed. Figure 3 shows the completely developed site. Assuming Items 1 through 6 above (General Conditions), Figure 3 reflects a developed site having the following characteristics:

1. Total capacity of 971,000 cu yd of dredged materials having:

   a) 363,000 cy yd of fine grained materials
   b) 608,000 cu yd of sand

2. 54 acres of Spartina alterniflora salt marsh developed on fine grained materials at elevations between 4.0 ft and 5.0 ft.

3. 13 acres of Spartina alterniflora salt marsh developed throughout the sand containment structure at elevations between 2.5 ft and 5.0 ft.

4. 13 acres of Spartina patens salt marsh developed throughout the sand containment structure at elevations between 5.0 ft and 6.0 ft.

4

Hammonasset State Park

Cedar I

Fines

Long Island Sound

(figure not to scale)

→ Continue as required for future dredging needs.

— — — — Centerline for permanent breakwater and sand containment structure.

▬▬▬▬ Permanent breakwater for initial dredging needs.

▭ Sand containment structure for fine grained materials.

⁚⁚⁚⁚⁚ Low profile temporary sand dike.
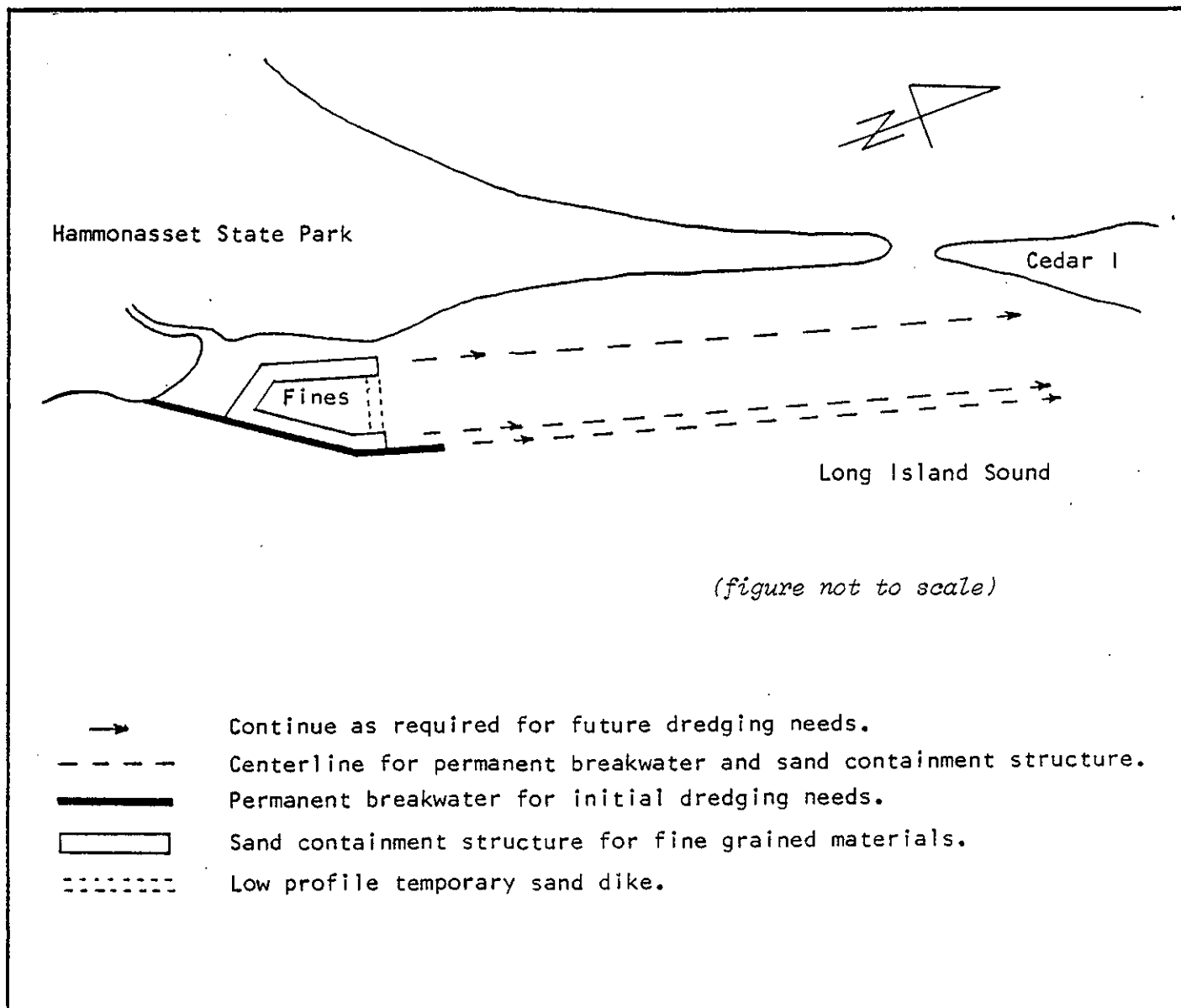
Figure 2. Sequential development scheme for dredged material
disposal and habitat development.

Cedar Island

Hammonasset State Park

9

MLW = 0'
MHW = 5.0'

Site Capacity:

363,000 cu yd fines
608,000 cu yd sand

Stone breakwater; el. 7'

13 acres unvegetated to sparsely vegetated upland nesting habitat; el. 6' to 7'

13 acres Spartina patens high saltmarsh habitat; el. 5/ to 6'

67 acres Spartina alterniflora low saltmarsh habitat; el. 2.5' to 5' (15 acres on containment interior - silts; 13 acres on containment exterior - sand)

15 acres of mud flat habitat; el. 0' to 2.5' (containment exterior)

28 acres of shallow water habitat; el. 1' to 0'

Sand dredged material mounds with 50:1 slopes to form containment

Figure 3. Distribution of wetland habitats on dredged material containment facility.

5. 15 acres of unvegetated intertidal sand flat at elevations between 0 ft and 2.5 ft.

6. 13 acres of unvegetated to sparsely vegetated sand nesting area at elevations between 6.0 ft and 7.0 ft.

7. 28 acres of shallow subtidal area at elevations between -1 ft and 0 ft.

The site capacity for dredged sand and fine grained materials and the areas of the different types of habitats will vary as the angle of repose of the dredged sand varies from the assumed value of 50 to 1. Steeper sloping sands will reduce the site capacity for sand and increase it for fines. They would provide smaller areas of nesting, habitat, S. patens, S. alterniflora (on containment exterior), and mud flat and a larger area of the contained fine grained dredged materials and associated S. alterniflora. More gently sloping sands will reverse the above trends.

Any consideration of alternative designs should not include the development of fine grained materials above the Mean High Water elevation. Such a development would produce supersaline conditions and desiccation cracks throughout the sediments above Mean High Water and would limit the successful establishment of any vegetation throughout these sediments.

3. Vegetative Development

The establishment of S. alterniflora between elevations 4.0 ft to 5.0 ft can be accomplished by seeding. The establishment of this species between elevations 2.5 ft and 4.0 ft and of S. patens between elevations 5.0 ft and 6.0 ft must be accomplished by transplanting peat-potted nursery stock. Sandy areas between elevations 6.0 ft and 7.0 ft might be sparsely vegetated by a combination of Panicum virgatum (switchgrass), Ammophila breviligulata (beachgrass), and Myrica pensylvanica (bayberry). Commercial nursery plant materials of these species are recommended. Regional plant materials or ones obtained from areas south to Virginia would be acceptable to use.

All of the above plant species with the exception of P. virgatum were found (Taxon, Inc. Biotic Survey) to occur naturally on Cedar Island. Panicum virgatum is found on dunes and sandy slopes from Canada south to the Gulf States and should develop well throughout the specified elevations on the habitat development site. All of the above species are commercially available.

Transplanting on a 2-foot grid and 3-foot grid requires 10,890 and 4,840 transplants per acre, respectively. For S. patens and S. alterniflora, a 2-foot planting grid would provide uniform vegetative cover within one full growing season. A 3-foot

grid would provide uniform vegetative cover within two growing seasons. If costs are not a limiting factor, the 2-foot grid is preferred over the 3-foot grid because of (1) rapid substrate stabilization, (2) reduction of ice damage due to ice removal of isolated transplants, and (3) reduction in depradation by geese and muskrats.

Approximate costs for seeding and transplanting (including fertilization) are $2,500 per acre and $1.25 per transplant, respectively.

APPENDIX A

CURRENT AND CIRCULATION SURVEY
OCEAN SURVEYS, INC.

TABLE OF CONTENTS

1.0 INTRODUCTION

The Clinton Harbor current and circulation surveys described herein were performed by Ocean Surveys, Inc. (OSI) during the period 4-13 November 1981, at the request of Taxon, Inc.

The specific purpose of this work was to obtain oceanographic information which could be used by The Center for the Environment and Man, Inc. (CEM) for predicting the potential impact of dredged material container dike(s) on circulation and flushing in Clinton Harbor.

2.0 PROJECT SUMMARY

OSI was contracted to acquire three (3) distinct types of oceanographic data, the first being continuous eulerian current data collected by deploying an in situ recording current meter for nine (9) days near Wheeler Rock, at the mouth of Clinton Harbor ("CM", Figure 1). The deployment period was designed so that the data would include both neap and spring tidal phases. The second type of data consisted of vertical current velocity profiles. These measurements were taken at two (2) points where the flow constricts when entering and leaving Clinton Harbor (stations "CH" and "HP", Figure 1). Station "BW" was occupied (rather than "HP") when the sea state was favorable.

The final phase of data acquisition entailed two (2) days of drogue tracking. Each day (11-12 November 1981) surface drogues were deployed and tracked during both the flood and ebb tides.

3.0 EQUIPMENT AND FIELD PROCEDURES

3.1 Current Meter Deployment

On 4 November 1981, OSI personnel deployed an Endeco Type 105 ducted impeller current meter in approximately nine (9) feet (MLW) of water at the mouth of Clinton Harbor. The meter itself was positioned on a taut line mooring at a height of four (4) feet above the bottom (Figure 2).

The Endeco 105 records current speed and direction by taking a direct photographic time exposure of sensor outputs. At Clinton Harbor, the meter was set at a recording rate of one (1) reading per 30 minutes. A specification sheet on the Endeco 105 is included in Appendix A.

On 13 November 1981, the current meter and mooring apparatus were retrieved after nine (9) days of deployment.

A-2
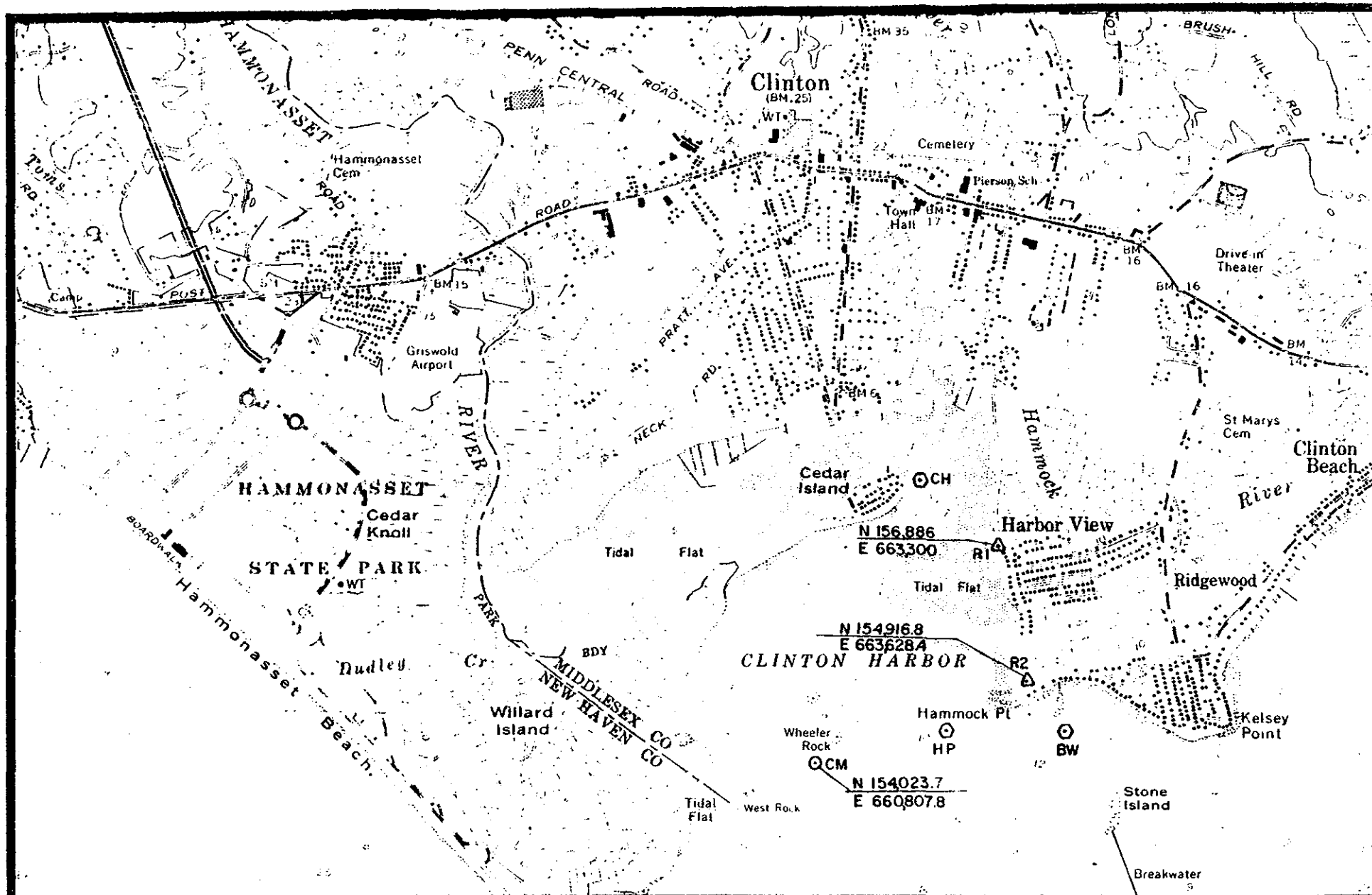
Clinton
(BM.25)

HAMMONASSET

STATE PARK

CLINTON HARBOR

N 156.886
E 663.300   R1

N 154.916.8
E 663.628.4   R2

N 154.023.7
E 660.807.8

FIGURE NO.		DATE		OCEAN SURVEYS, INC.
	1		25·NOV·81	
SCALE		BY		OLD SAYBROOK, CONNECTICUT
	1:24000		CRR	

SCALE 1:24000

CLINTON HARBOR CURRENT METER DESIGN

SUBSURFACE BUOY

ENDECO 105
CURRENT METER

1'

4'

ACOUSTIC PINGER

175 LBS LEAD

DANFORTH ANCHOR

A-3
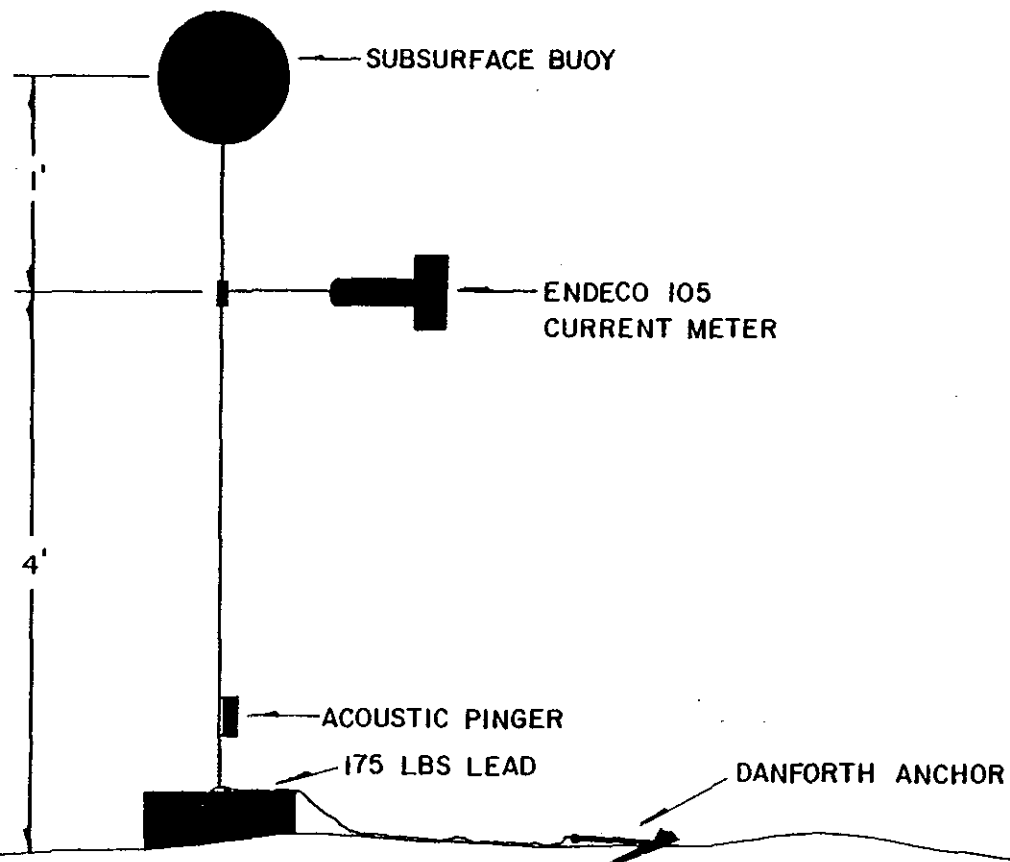
FIGURE NO. 2	DATE 25·NOV·81	**OCEAN SURVEYS, INC.** OSI
SCALE N.T.S.	BY CRR	OLD SAYBROOK, CONNECTICUT

3.2 Vertical Profiling

Vertical current velocity profiling was performed at stations "CH", "HP" and/or "BW" (see Figure 1) employing an Endeco Type 110 remote reading current meter. This instrument provides information on four (4) parameters: current speed, current direction, water temperature, and sensor depth. Readings of all four parameters were recorder at two (2) foot (vertical) intervals. A specification sheet on the Endeco 110 is provided in Appendix A.

To assure location stability at each profiling station, the vessel was secured in place by employing a two (2) point mooring. On station the current meter was checked for proper calibration. The time was then recorded and readings initiated. The vertical profiling data, as well as pertinent meteorological, sea state and location information, are listed in Tables 1-3.

Profiling was conducted at stations "CH" and "BW" or "HP" during both flooding and ebbing tides in order to characterize the current regimes at these points. Vertical profiling was performed on two occasions at station "CM" to permit comparison between the two types of eulerian data. Agreement between the corresponding sets of data is excellent: 0.01 fps and 16° on 4 November 1981, and 0.17 fps and 3° on 13 November (see Tables 1 and 3, Station "CM" and computer listings in Appendix B).

3.3 Drogue Tracking

The surface drogues employed during this survey were designed and constructed by OSI. They were built from plywood and weighted with lead so that only a small portion of the Styrofoam float and the stenciled flag were exposed above the water surface (Figure 3).

A Cubic "Autotape" DM-40A dual range electronic positioning system was employed for tracking the surface drogues. This system is comprised of three (3) components: two responder units and an interrogator unit. Range measurements are obtained by microwave phase comparison between the shipboard interrogator and each of the two shore-based responders providing extremely accurate range measurements between the vessel and the shore stations. The two (2) ranges are automatically displayed, in meters, by the onboard interrogator at a one second rate. The accuracy of the indicated vessel position at each one second "fix" is nominally $\pm$ 1.0 meters and is virtually unaffected by atmospheric conditions. A specification sheet on the Cubic DM-40A "Autotape" is included in Appendix A.

TABLE 1

CLINTON HARBOR CURRENT AND CIRCULATION SURVEY
VERTICAL CURRENT PROFILE
4 November 1981

Station	Depth (ft)	Speed (fps)	Direction (True)	Temp. (°C)	Comments
"CM"	8.0 6.0 3.9 2.0	0.17 0.34 0.25 0.17	257 272 273 282	13.1 12.9 12.9 12.9	·T = 1123 ·Flood Tide ·Profile at current meter ·Wind speed = 6-8mph ·Direction = 240°
"BW"	8.9 4.5 2.5 0.5	0.84 1.10 1.18 1.35	017 012 009 009	14.0 13.2 13.2 13.0	·T = 1200 ·Flood Tide ·On line between breakwater and Hammock Point ·Seas = 1-1.5 ft.
"CH"	9.8 7.2 6.2 3.8 1.8 0.5	0.93 1.18 1.22 1.15 1.05 1.05	352 355 007 017 012 007	12.8 12.9 12.8 12.8 12.8 12.9	·T = 1212 ·Flood Tide ·25 ft southwest of buoy "N10" ·Calm in channel

TABLE 2

CLINTON HARBOR CURRENT AND CIRCULATION SURVEY
VERTICAL CURRENT PROFILE
11 November 1981

Station	Depth (ft)	Speed (fps)	Direction (True)	Temp. (°C)	Comments
"CH"	12.5	0.88	009	10.8	·T = 0758
	11.0	0.93	009	10.8	·Flood Tide
	9.5	0.93	007	10.8	·Wind Speed = 4 mph
	7.0	0.96	007	10.8	·Direction = 210°
	5.3	0.88	004	10.8	·25' Southwest of
	3.5	0.89	007	10.8	Buoy "N10"
	1.0	0.84	017	10.8	
"HP"	7.0	0.13	122	10.9	·T = 1415
	5.0	0.14	122	10.9	·Ebb Tide
	3.0	0.25	122	10.9	·Wind Speed = 10-12
	1.0	0.25	122	11.0	mph
					·Direction = 210°
					·Sea State = 1-2'
"CH"	5.0	2.16	212	10.3	·T = 1435
	3.1	2.11	202	10.2	·Ebb Tide
	1.0	2.19	202	10.2	·Calmer in channel
					·25' Southwest of
					Buoy "N10"

Remarks – First day of drogue work
Spring tidal conditions
Strong Southwest wind

TABLE 3

CLINTON HARBOR CURRENT AND CIRCULATION SURVEY
VERTICAL CURRENT PROFILE
13 November 1981

Station	Depth (ft)	Speed (fps)	Direction (True)	Temp. (^oC)	Comments
"CH"	13.5	0.81	012	9.9	·T = 1008
	11.1	1.01	005	9.9	·Flood Tide
	10.3	0.91	007	9.9	·Wind Speed= 4-5 mph
	9.2	0.93	007	10.0	·Direction = 045º
	7.0	0.84	009	10.0	·25' Southwest of
	5.1	0.89	015	10.0	Buoy "N10"
	2.8	1.35	015	10.0	
"CM"	13.5	0.30	355	9.8	·T = 1017
	10.5	0.34	357	9.8	·Flood Tide
	9.0	0.34	017	9.8	·Profile at current
	7.0	0.42	017	9.8	meter
	4.5	0.42	017	9.8	
	3.0	0.34	002	9.8	
	1.0	0.34	002	9.9	
"BW"	11.5	0.51	247	10.2	·T = 1040
	11.0	0.51	252	10.2	·Flood Tide
	8.5	0.42	242	10.3	·Profile on line
	7.0	0.54	237	10.3	between breakwater
	5.0	0.51	237	10.3	and Hammock Point
	2.5	0.51	237	10.3	
	1.0	0.51	247	10.3	

Remarks - Current meter removed 1110

NYLON PENNANT

SURFACE FLOAT

9" X 12" PLYWOOD PANELS

BALLAST

OSI DROGUE DESIGN

A-8
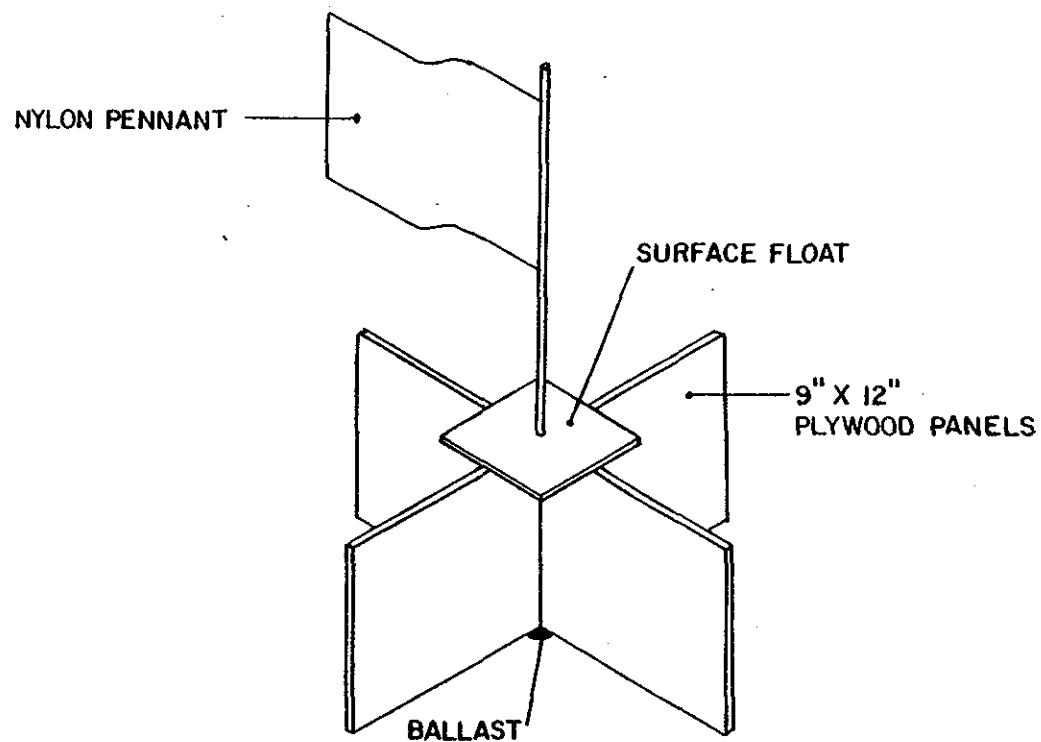
FIGURE NO. 3	DATE 25·NOV·81	**OCEAN SURVEYS, INC.**
SCALE N.T.S	BY CRR	OLD SAYBROOK, CONNECTICUT

At Clinton Harbor, the vessel was conned to each drogue in turn. When the interrogator antenna was directly beside the floating drogue, a position "fix" was noted. These range readings were recorded into field survey logs, and the approximate location of each drogue was plotted onboard. This last step was performed to monitor the movement of the drogues for relocation purposes and to verify positioning data.

The drogues were deployed along lines which provided maximum coverage of the study area. Position determinations for each drogue were made at intervals of 10 to 25 minutes. The drogues were tracked throughout the study area and were recovered only when they approached shore, entered water too rough, or passed south of an imaginary line extending between West Rock and Hammock Point.

4.0   DATA PROCESSING PRESENTATION

4.1   Current Meter Data

Data recorded onto film by the Endeco 105 is represented as a series of time exposure bar graphs. By determining the percentage of full scale of a particular bar graph, it is possible to determine an average current velocity over a particular exposure interval. Nine days of data for Clinton Harbor were processed in this fashion and are presented in Appendix B as computer listings of time, current speed and current direction for each day of recording.

Table 4 is a list of the predicted times of high slack and low slack water during the survey period, and is provided for the convenient determination of tidal stage.

4.2   Drogue Tracking Data

Recorded fix times were combined with "Autotape" range information to reconstruct drogue tracks and to compute an average drogue speed between fixes. This information is presented on plan view drawings 72163-A through 72163-D at a scale of 1" = 200'.

Sea state and meteorological conditions during the drogue tracking phase of the current and circulation survey are listed in Table 5.

5.0   DISCUSSION OF DATA

During the Clinton Harbor oceanographic survey, OSI employed two (2) control points: "HAMM 80" and "West." In speaking with officials from the New England Corps of Engineers, we found that they believe the coordinates of "HAMM 80" to be inaccurate "by as much as ± 2 feet." For this survey, errors of this magnitude do not significantly affect the results.

TABLE 4

CLINTON HARBOR CURRENT AND CIRCULATION SURVEY
TIDE PREDICTIONS*
4-13 November 1981

Date	Low Slack	High Slack	Low Slack	High Slack	Low Slack
4 Nov.		0330	0939	1542	2216
5 Nov.		0426	1041	1643	2310
6 Nov.		0522	1140	1743	0002
7 Nov.		0615	1233	1839	
8 Nov.	0051	0706	1324	1933	
9 Nov.	0138	0755	1412	2024	
10 Nov.	0224	0844	1501	2115	
11 Nov.	0311	0932	1549	2205	
12 Nov.	0359	1021	1639	2256	
13 Nov.	0450	1112	1731	2348	

NOAA Tidal Current Tables 1981   S/T 80-248

*Predictions listed are for times located half
way between Kelsey and Hammonasset Points.

TABLE 5

CLINTON HARBOR CURRENT AND CIRCULATION SURVEY
SEA STATE AND METEOROLOGICAL CONDITIONS DURING DROGUE TRACKING
11-12 November 1981

Date	Time	Sea State	Wind Speed	Wind Direction	Remarks
11 Nov.	0842	0.5-1.0 ft	4 - 6 mph	197° true	Begin drogue tracking
	0940	0.5-0.8 ft	4 - 5 mph	197° true	Gusts to 8 mph
	1132	0.8-1.0 ft	7 - 8 mph	232° true	Gusts to 10 mph
	1228	0.8-1.0 ft	7 - 8 mph	230° true	Seas building
	1353	1.0-1.5 ft	8 -10 mph	232° true	End of daily operations
12 Nov.	0758	0.3-0.5 ft	7 - 8 mph	2° true	Begin drogue tracking
	0920	0.8-0.9 ft	7 - 8 mph	332° true	Gusts to 10 mph
	1110	0.4-0.6 ft	3 - 5 mph	17° true	Gusts to 8 mph
	1300	0.4-0.6 ft	4 - 6 mph	12° true	Gusts to 8 mph End of drogue tracking.

The shorelines of Drawings 72163-A through 72163-D were plotted using OSI's tablet digitizer*, "Autotape" range measurements, and field observations.

Drawing 72163-C shows that drogue passes very closely to the current meter "CM" during deployment #3 (position fixes 1-2, T = 0800). This provides the opportunity to compare the in situ current meter and drogue data. We find that the surficial currents are 0.35 fps less than those at a depth of nearly 9 feet, and the direction of this movement is approximately $30°$ (+ $23°$ from the current meter). This large speed differential results from the circulation pattern set up by lunar, meteorological, and tidal conditions. Higher velocities are to be expected at depth during a flooding spring tide when surficial wind stresses from the northeast act to force water out of Clinton Harbor.

*From NOAA (1976) Nautical Chart 12372, Page D, Inset 5.

APPENDIX A

EQUIPMENT SPECIFICATION SHEETS

ENDECO

TYPE 105 SELF-CONTAINED TETHERED CURRENT METER

FEATURES:

- REDUCED WAVE ERROR
   FLOW REVERSIBLE
      IMPELLER
   UNIQUE TETHER DESIGN
- HIGHEST DATA RETURN IN
   THE INDUSTRY
- DESIGNED FOR FIELD USE
   EASILY SERVICED
   DIVER INSTALLABLE
   NEUTRALLY BUOYANT
   LIGHT WEIGHT
   RUGGED CASE AND
      MECHANISM
- INTEGRATED DATA
   RECORDING
- TWO WEEK DATA
   TURNAROUND
- LOW INSTRUMENT AND
   DATA COST
- DELIVERY FROM STOCK

ENVIRONMENTAL DEVICES CORPORATION

MARION, MASSACHUSETTS 02738
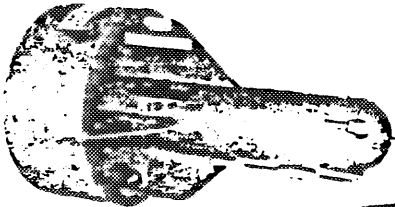
THE ENDECO PROPRIETARY TE-THER design and the flow reversible impeller combine to allow the instrument to cancel wave induced errors.

EXCELLENT DATA RETURN is accomplished by maintaining the ENDECO philosophy of simplicity in design. Rugged mechanical components and a solid state Type 124 Crystal Timer assure high accuracy. A unique bearing design maintains a very conservative rotor accuracy specification of ±3 percent during long periods of field use. In addition, every instrument is individually calibrated, producing computer stored compensations for use during data reduction.
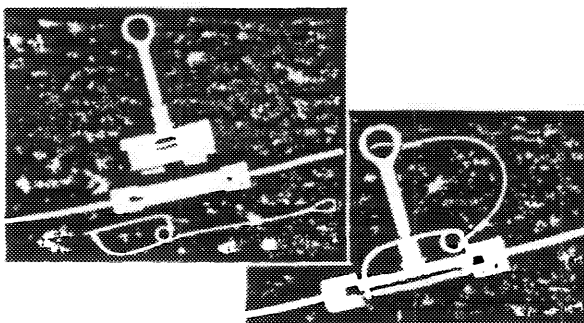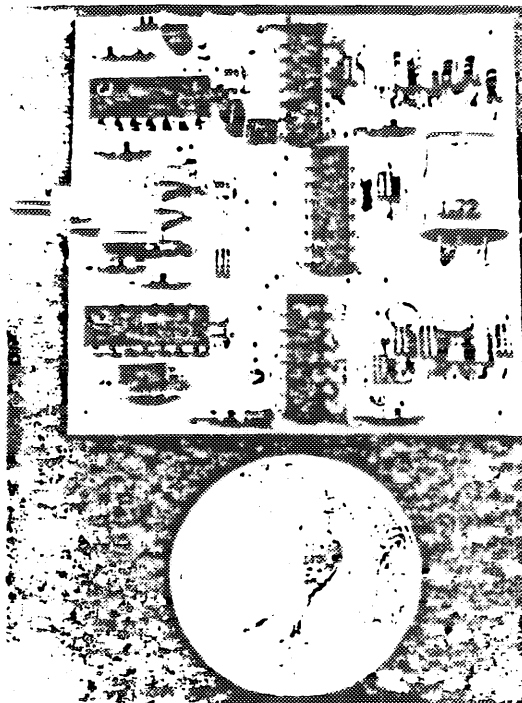
FIELD USE IS SIMPLIFIED through a design that is oriented to the field service technician. A quick-release clamp is provided for easy field installation. Divers find the neutrally buoyant instrument very easy to handle in water. Only minimum maintenance of the Type 105 is required inside and out. Servicing requires no more than changing standard size flashlight batteries and the daylight loaded film pack. Outside, the instrument case is non-corrosive shock absorbing plastic. coated with anti-fouling protection to withstand rigorous field conditions.

DETAILED SPECIFICATIONS

1. CURRENT VELOCITY

Sensor type:	Ducted Impeller
Sensitivity:	53.7 RPM/knot
Speed Range:	0 - 1.75 knots (0-90.1 cm/sec) at 1 Reading/60 minutes
	0 - 3.5 knots (0-180.2 cm/sec) at 1 Reading/30 minutes
	0 - 7.0 knots (0-360.4 cm/sec) at 1 Reading/15 minutes
Impeller Threshold:	Less than .05 knot (2.57 cm/sec)
Resolution:	.05 knot
Speed Accuracy:	±3 percent of Full Scale

2. CURRENT DIRECTION

Magnetic Direction:	0 - 360°
Sensitivity:	±5° at 0.05 knot (2.57 cm/sec)
Resolution:	±1°

Accuracy:	2 percent above 0.05 knot, when referenced to computer calibration

3. TILT

The instrument orients to the flow thus eliminating the need for tilt indication or correction.

4. RECORDING TIME AND RATE

Number of Readings:	3600
Recording Rate:	1 Reading/15 minutes 1 Reading/30 minutes 1 Reading/60 minutes
Time Reference Mark:	24 hour Light Emitting Diode indication provided by timer
Maximum Recording Period:	75 days at 1 Reading/ 30 minutes
Time Stability:	±1.5 second/day at 20°C ±4 second/day from −5 to +30°C
Timer Type:	ENDECO Type 124 Crystal Timer
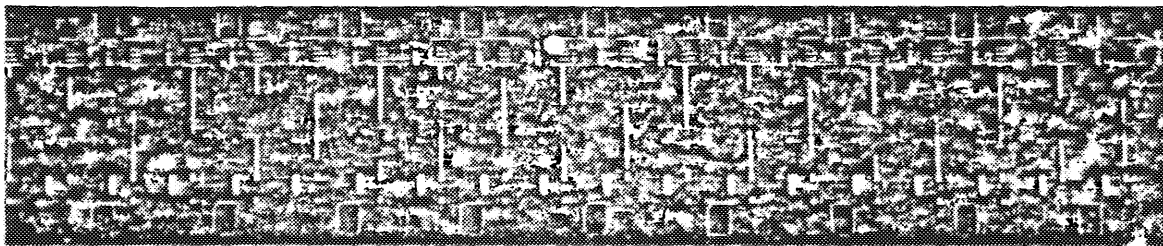
TWO WEEK TURNAROUND of data at ENDECO is guaranteed. ENDECO goes one step further by providing custom field service of instruments to assure highest recovery of data.

LOWER COST PER INSTRUMENT is accomplished through the use of plastic parts and ENDECO's philosophy of simple design.

TYPE 105 TCM
INSTRUMENT/DATA PATH

FIELD DATA

DIGITAL CONVERSION

PUNCHED PAPER TAPE

SPEED CALIBRATION

COMPUTER

STANDARD PLOT

STANDARD REPORT

COMPASS CALIBRATION

VECTOR ANALYSIS AND STATISTICS

Compass and speed curves for each instrument are computer-stored for later data compensation.
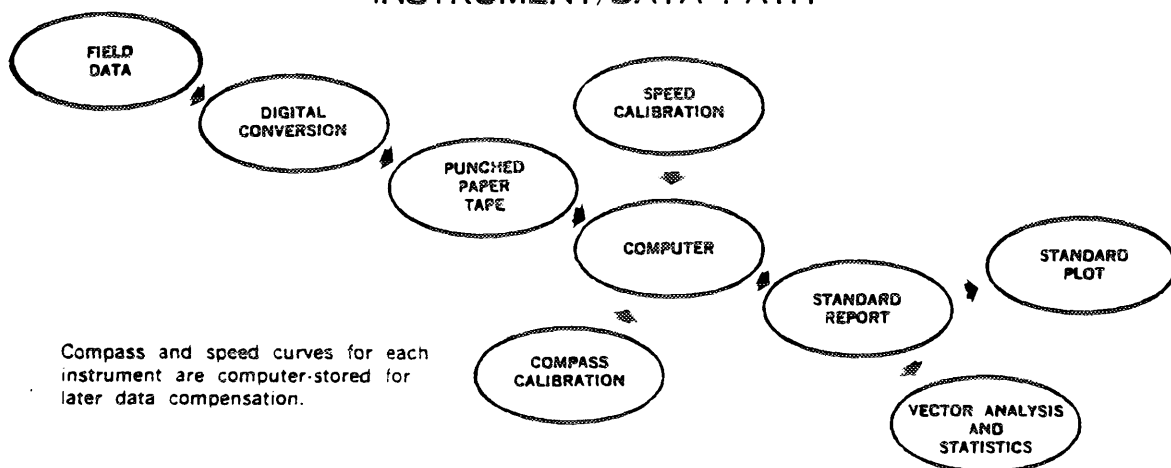
5. RECORDER

Method:	Direct photographic time exposure of sensor outputs
Light Source:	Light Emitting Diodes continuously energized
Format:	Analog/Bar Graph
Film Cartridge:	50 feet · 16mm Cine Kodak Magazine
Film Type:	Kodak Tri-X
Power:	Four, 1½ volt standard "D" size cells

6. OPERATING ENVIRONMENT

Operating Medium:	Salt, fresh, or polluted water
Operating Temperature Range:	–2° to 45°C (28° to 113°F)
Storage Temperature Range:	–34° to 65°C (–29° to 149°F)

Maximum Depth:	500 feet (pressure cases to 10,000 psi available)

7. INSTRUMENT HOUSING

Material:	P.V.C. Plastic
Finish:	All surfaces painted for resistance to marine growth
Hardware:	300 Series Stainless Steel and Plastic

8. PHYSICAL SIZE

Weight:	27 pounds (in air)
Buoyancy:	Approximately neutral; adjustable for salt, fresh, or polluted water
Dimensions:	30″ long x 16″ diameter
Shipping Weight:	45 pounds
Shipping Crate Dimensions:	38″ long x 22″ diameter

ENDECO

TYPE 110 REMOTE READING CURRENT METER
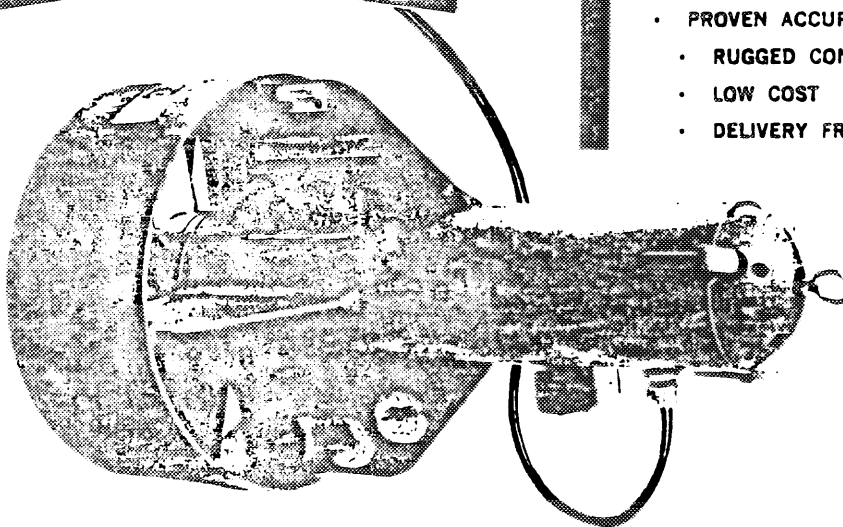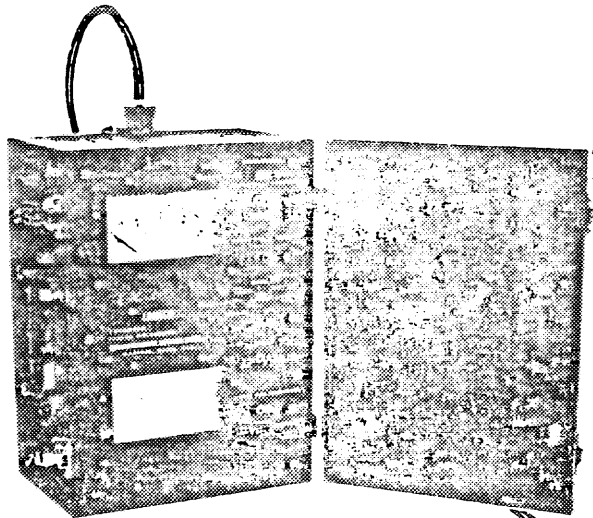
FEATURES:

- MEASURES FOUR PARAMETERS:
  - CURRENT SPEED
  - CURRENT DIRECTION
  - WATER TEMPERATURE
  - INSTRUMENT DEPTH

- SMALL BOAT ADAPTABLE:
  - COMPLETELY SELF-CONTAINED
  - LIGHTWEIGHT
  - BOAT AND WAVE MOTION CANCELLING

- PROVEN ACCURACY
  - RUGGED CONSTRUCTION
  - LOW COST
  - DELIVERY FROM STOCK

ENVIRONMENTAL DEVICES CORPORATION
MARION, MASSACHUSETTS 02738
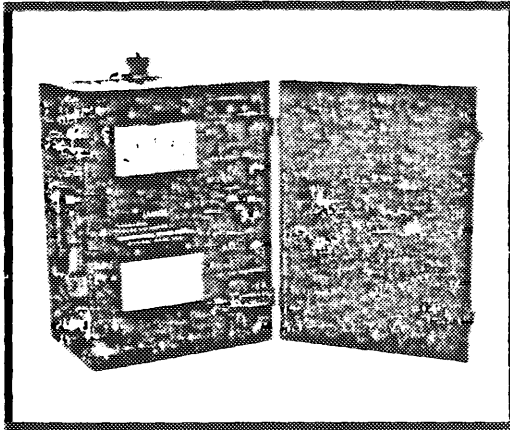
FOUR PARAMETERS IN ONE ASSEMBLY — current speed, current direction, water temperature, and instrument depth—means only one instrument on board where space is at a premium.
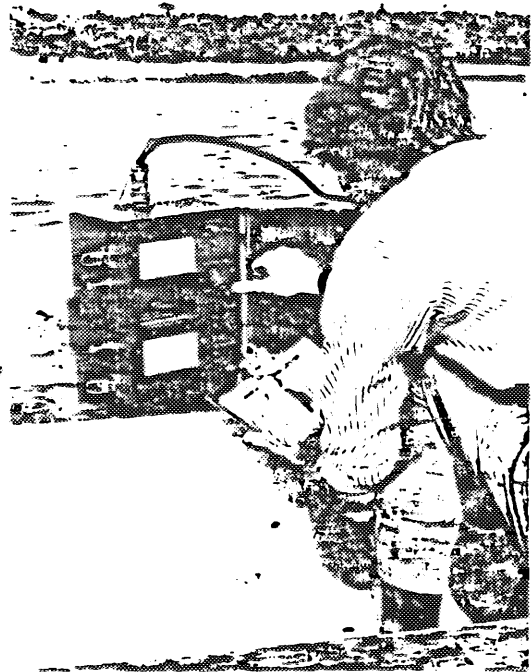
SMALL BOAT ADAPTABILITY is accomplished in several ways. No external power source is necessary with the completely self-contained unit; the light weight of the instrument makes it convenient to handle and deploy. The ENDECO tether design cancels boat and wave motion, allowing accurate readings of low currents in a wave field. For longer duration applications or when room permits, an external 12 volt D.C. power source may be used.

Type 110 Lower Unit

CURRENT SPEED SENSOR:
Ducted impeller and reed switch

Range:	0 to 5 knots (0 to 257 cm./sec.)
Accuracy:	±3 percent of full scale
Threshold:	Less than .05 knots (2.57 cm./sec.)

CURRENT DIRECTION SENSOR:
Magnetic compass with potentiometer

Range:	0 - 360° (0 - 357° Electrical)
Accuracy:	±3 percent of full scale
Threshold:	.05 knot

DEPTH SENSOR:
Pressure operated potentiometer

Range:	0 - 100 feet. (Other ranges available).
Accuracy:	±2 percent of full scale
Overpressure:	1.5 x full scale

Sensor Isolation:	Oil filled isolator with neoprene diaphragm for corrosion protection of sensor.

TEMPERATURE SENSOR:
Linear glass bead thermistor

Range:	0° to 40°C
Accuracy:	±0.5°C

OPERATING ENVIRONMENT

Operating Medium:	Salt, fresh or polluted water.
Operating Temperature Range:	0° to 40°C (32° to 104°F)
Storage Temperature Range:	—34 to 65°C (—29 to 149°F)
Maximum Pressure:	500 psi (Pressure cases to 10,000 psi available)
Maximum Mooring Tensile Load:	250 pounds

OCEAN SURVEYS, INC.
OLD SAYBROOK, CONNECTICUT

AUTOTAPE DM-40A

Automatic positioning system for ships, dredges and helicopters
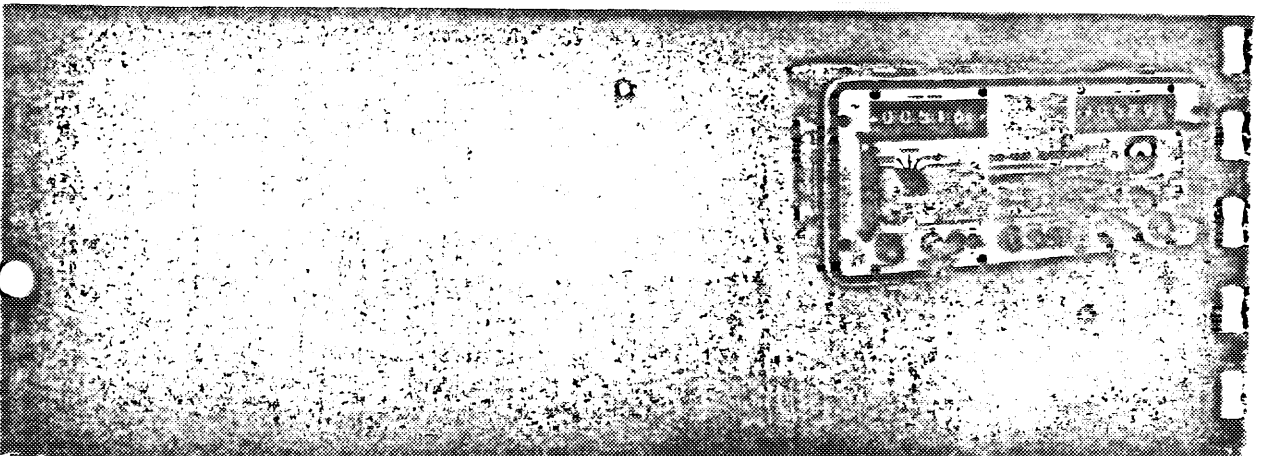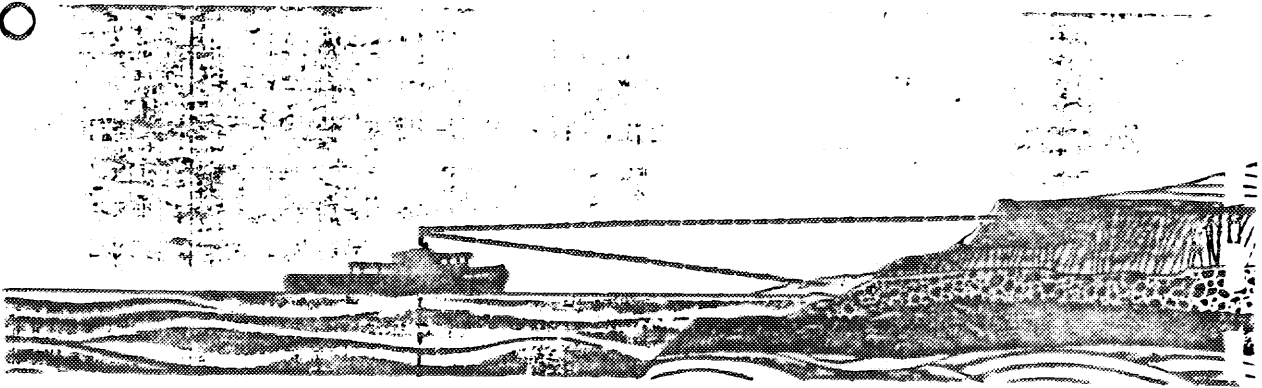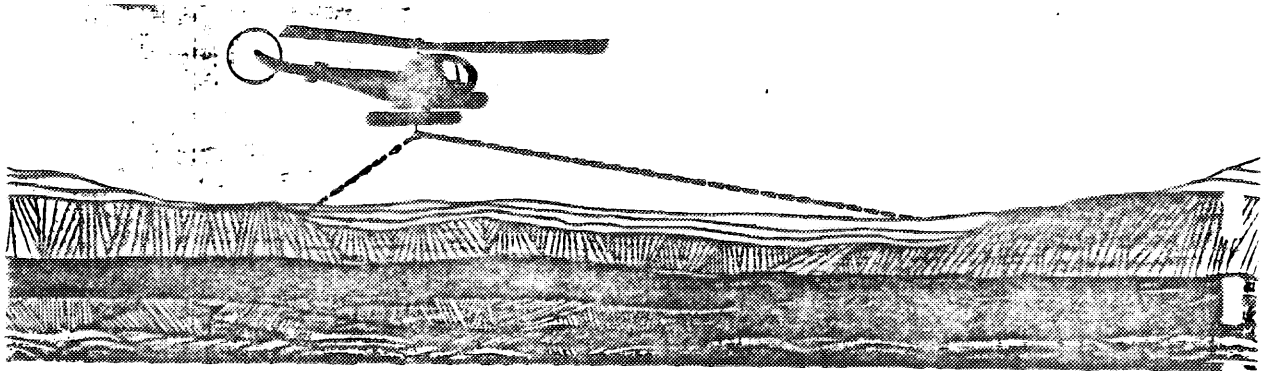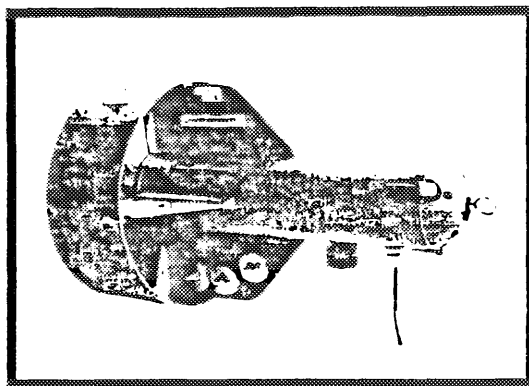
RUGGED CONSTRUCTION ensures that each ENDECO instrument will take the rough treatment found in the field. The instrument case is constructed from shock-absorbing resilient plastic, giving a lightweight, corrosion-resistant package. The polyurethane jacketed cable contains an anti-hosing material that automatically stops water from penetrating and injuring interior instrument components should the jacket be broken. An auxiliary rope connected to the submerged instrument and clipped to the telemetering cable carries all tension, thus protecting the electrical cable from stress and injury.

PROVEN ACCURACY is designed into the Type 110. The simplified design has fewer parts to malfunction. Extensive testing and quality control is performed on each instrument with individual rotors tested in flow channels at 2.0 ft. per sec. (60.1 cm. per sec.). A further test at 0.085 ft. per sec. (2.6 cm. per sec.) is performed on individual rotor thresholds.
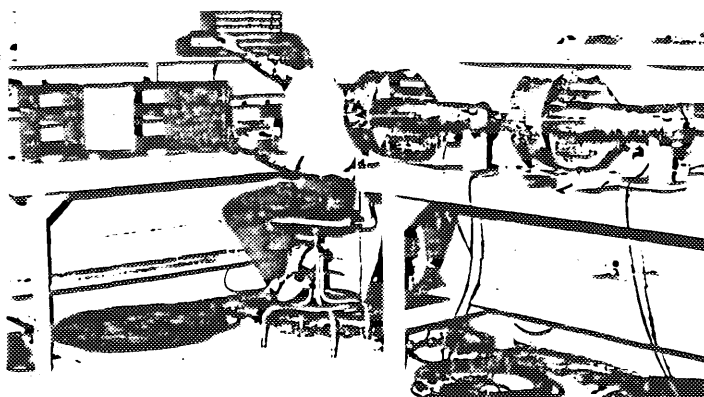
FICATIONS

INSTRUMENT HOUSING:

Material:	P.V.C. plastic
Finish:	Anti-fouling painted surface
Hardware:	300 Series Stainless Steel

PHYSICAL SIZE:

Weight:	40 pounds in air
Weight in sea water:	Approximately neutrally buoyant
Dimensions:	30" long x. 16" diameter

Type 110 Deck Readout

Readout Meters:	6" square
Meter Calibrations:	
Speed:	0 - 5 knots
Direction:	0 - 360° magnetic north
Temperature:	0 - 40°C
Depth:	0 - 100 feet
Power:	Eight 1½ volt standard "D" cells

OPERATING ENVIRONMENT:

Operating Temperature Range:	0° to 40°C (32° to 104°F)
Storage Temperature Range:	−34° to 65°C (−29° to 149°F)

DECK READOUT HOUSING:

Material:	Corrosion resistant formica case.
Hardware:	300 Series Stainless Steel and chrome plated brass.

PHYSICAL SIZE:

Weight:	Approximately 14 pounds
Dimensions:	10" high x 13" wide x 10" deep.

SHIPPING CRATE DATA (Whole System):

Dimensions:	39" high x 22" diameter
Weight:	75 pounds

APPENDIX B

CURRENT METER DATA

CLINTON HARBOR CURRENT DATA

CLINTON CONNECTICUT

DATA DATE:12 NOV 1981

TIME	SPD(fts)	DIR(tru)	TIME	SPD(fts)	DIR(tru)
30	0.30	161	100	0.24	162
130	0.24	170	200	0.24	166
230	0.12	156	300	0.06	145
330	0.18	190	400	0.24	218
430	0.36	256	500	0.42	268
530	0.30	256	600	0.12	279
630	0.30	328	700	0.54	359
730	0.48	1	800	0.71	7
830	0.71	16	900	0.66	23
930	0.83	36	1000	0.89	44
1030	0.60	42	1100	0.36	59
1130	0.24	109	1200	0.24	123
1230	0.24	135	1300	0.30	162
1330	0.30	170	1400	0.60	172
1430	0.36	165	1500	0.18	140
1530	0.12	128	1600	0.24	218
1630	0.48	224	1700	0.48	251
1730	0.42	259	1800	0.30	275
1830	0.18	298	1900	0.24	331
1930	0.54	16	2000	0.42	19
2030	0.42	6	2100	0.42	22
2130	0.60	33	2200	0.83	47
2230	0.66	53	2300	0.60	42
2330	0.42	42	2400	0.24	50

DATA DATE:13 NOV 1981

TIME	SPD(fts)	DIR(tru)	TIME	SPD(fts)	DIR(tru)
30	0.12	142	100	0.42	166
130	0.54	166	200	0.42	170
230	0.42	177	300	0.36	174
330	0.30	166	400	0.24	192
430	0.66	214	500	0.54	229
530	0.42	264	600	0.24	263
630	0.18	281	700	0.24	306
730	0.42	14	800	0.60	24
830	0.60	26	900	0.77	28
930	0.66	18	1000	0.54	22
1030	0.54	14	1100	0.42	333

CLINTON HARBOR CURRENT DATA

CLINTON CONNECTICUT

DATA DATE:10 NOV 1981

TIME	SPD(fts)	DIR(tru)	TIME	SPD(fts)	DIR(tru)
30	0.48	198	100	0.12	210
130	0.30	230	200	0.36	244
230	0.42	251	300	0.36	268
330	0.24	273	400	0.24	276
430	0.24	297	500	0.24	335
530	0.48	7	600	0.60	20
630	0.66	22	700	0.48	4
730	0.36	330	800	0.42	337
830	0.71	54	900	0.60	47
930	0.30	45	1000	0.06	38
1030	0.06	66	1100	0.12	83
1130	0.36	153	1200	0.42	162
1230	0.42	172	1300	0.36	174
1330	0.24	148	1400	0.30	181
1430	0.36	228	1500	0.60	231
1530	0.54	256	1600	0.30	234
1630	0.12	220	1700	0.06	245
1730	0.06	306	1800	0.66	30
1830	0.42	25	1900	0.42	23
1930	0.48	29	2000	0.60	48
2030	0.77	65	2100	0.66	62
2130	0.66	51	2200	0.42	50
2230	0.12	61	2300	0.06	282
2330	0.30	197	2400	0.36	182

DATA DATE:11 NOV 1981

TIME	SPD(fts)	DIR(tru)	TIME	SPD(fts)	DIR(tru)
30	0.60	179	100	0.48	182
130	0.42	194	200	0.30	206
230	0.36	221	300	0.60	232
330	0.36	255	400	0.24	262
430	0.18	288	500	0.12	343
530	0.42	37	600	0.54	42
630	0.54	41	700	0.42	37
730	0.71	37	800	0.54	52
830	0.48	57	900	0.48	59
930	0.66	55	1000	0.48	53
1030	0.30	53	1100	0.12	320
1130	0.24	224	1200	0.24	214
1230	0.66	191	1300	0.42	185
1330	0.42	174	1400	0.30	151
1430	0.36	150	1500	0.42	148
1530	0.12	206	1600	0.36	252
1630	0.48	270	1700	0.48	269
1730	0.30	282	1800	0.18	316
1830	0.42	336	1900	0.48	19
1930	0.54	26	2000	0.48	17
2030	0.42	19	2100	0.42	30
2130	0.60	39	2200	0.71	58
2230	0.36	66	2300	0.24	136
2330	0.36	158	2400	0.42	163

CLINTON HARBOR CURRENT DATA

CLINTON CONNECTICUT

DATA DATE: 8 NOV 1981

TIME	SPD(fts)	DIR(tru)	TIME	SPD(fts)	DIR(tru)
30	0.12	260	100	0.24	286
130	0.24	277	200	0.36	290
230	0.36	294	300	0.36	295
330	0.42	321	400	0.42	324
430	0.30	329	500	0.36	352
530	0.36	12	600	0.36	35
630	0.36	45	700	0.42	43
730	0.30	61	800	0.30	104
830	0.18	116	900	0.12	130
930	0.24	120	1000	0.30	101
1030	0.24	93	1100	0.30	97
1130	0.18	114	1200	0.12	132
1230	0.12	161	1300	0.18	254
1330	0.30	272	1400	0.48	277
1430	0.42	281	1500	0.30	289
1530	0.36	300	1600	0.30	304
1630	0.30	308	1700	0.30	324
1730	0.30	330	1800	0.24	329
1830	0.30	342	1900	0.30	10
1930	0.42	49	2000	0.48	53
2030	0.30	35	2100	0.12	25
2130	0.00	168	2200	0.12	172
2230	0.24	151	2300	0.18	144
2330	0.24	155	2400	0.18	169

DATA DATE: 9 NOV 1981

TIME	SPD(fts)	DIR(tru)	TIME	SPD(fts)	DIR(tru)
30	0.18	229	100	0.36	253
130	0.36	240	200	0.42	247
230	0.30	260	300	0.30	272
330	0.18	283	400	0.18	326
430	0.24	346	500	0.42	1
530	0.42	24	600	0.60	21
630	0.42	28	700	0.60	43
730	0.71	53	800	1.01	55
830	0.54	50	900	0.24	119
930	0.18	129	1000	0.24	151
1030	0.30	163	1100	0.36	169
1130	0.30	145	1200	0.36	145
1230	0.36	131	1300	0.30	126
1330	0.18	130	1400	0.24	142
1430	0.24	255	1500	0.42	257
1530	0.48	270	1600	0.30	274
1630	0.30	296	1700	0.48	326
1730	0.42	345	1800	0.54	348
1830	0.48	6	1900	0.54	16
1930	0.54	19	2000	0.60	42
2030	0.60	50	2100	0.42	41
2130	0.18	117	2200	0.18	158
2230	0.24	218	2300	0.36	184
2330	0.30	172	2400	0.24	196

CLINTON HARBOR CURRENT DATA

CLINTON CONNECTICUT

DATA DATE: 6 NOV 1981

TIME	SPD(fts)	DIR(tru)	TIME	SPD(fts)	DIR(tru)
30	0.24	264	100	0.12	262
130	0.00	270	200	0.06	339
230	0.12	299	300	0.12	279
330	0.18	266	400	0.24	259
430	0.12	278	500	0.00	271
530	0.00	248	600	0.06	33
630	0.18	22	700	0.12	149
730	0.36	170	800	0.18	117
830	0.30	139	900	0.36	188
930	0.36	194	1000	0.36	196
1030	0.24	249	1100	0.42	272
1130	0.42	286	1200	0.30	298
1230	0.24	311	1300	0.30	319
1330	0.24	319	1400	0.30	337
1430	0.36	346	1500	0.30	357
1530	0.24	358	1600	0.24	12
1630	0.42	42	1700	0.54	47
1730	0.54	38	1800	0.42	39
1830	0.30	38	1900	0.24	48
1930	0.18	36	2000	0.12	11
2030	0.24	79	2100	0.24	80
2130	0.06	47	2200	0.12	338
2230	0.18	335	2300	0.12	297
2330	0.36	297	2400	0.30	311

DATA DATE: 7 NOV 1981

TIME	SPD(fts)	DIR(tru)	TIME	SPD(fts)	DIR(tru)
30	0.12	324	100	0.30	309
130	0.30	320	200	0.30	329
230	0.42	334	300	0.42	330
330	0.48	336	400	0.42	0
430	0.36	7	500	0.54	17
530	0.42	31	600	0.42	40
630	0.30	47	700	0.12	63
730	0.12	91	800	0.12	122
830	0.12	119	900	0.24	100
930	0.24	91	1000	0.30	83
1030	0.18	76	1100	0.18	66
1130	0.24	61	1200	0.18	46
1230	0.24	34	1300	0.24	31
1330	0.30	16	1400	0.24	4
1430	0.36	4	1500	0.30	1
1530	0.36	16	1600	0.36	19
1630	0.60	24	1700	0.42	29
1730	0.48	31	1800	0.42	38
1830	0.48	42	1900	0.30	48
1930	0.24	61	2000	0.18	91
2030	0.18	111	2100	0.06	131
2130	0.12	111	2200	0.18	108
2230	0.18	113	2300	0.24	107
2330	0.24	105	2400	0.12	123

CLINTON HARBOR CURRENT DATA

CLINTON CONNECTICUT

DATA DATE: 4 NOV 1981

TIME	SPD(fts)	DIR(tru)	TIME	SPD(fts)	DIR(tru)
1130	0.24	289	1200	0.24	301
1230	0.24	304	1300	0.18	321
1330	0.30	342	1400	0.24	20
1430	0.30	22	1500	0.42	53
1530	0.60	54	1600	0.54	63
1630	0.36	83	1700	0.30	114
1730	0.12	143	1800	0.18	139
1830	0.12	136	1900	0.18	141
1930	0.12	140	2000	0.12	148
2030	0.12	166	2100	0.18	166
2130	0.18	208	2200	0.30	220
2230	0.36	229	2300	0.30	249
2330	0.30	257	2400	0.12	242

DATA DATE: 5 NOV 1981

TIME	SPD(fts)	DIR(tru)	TIME	SPD(fts)	DIR(tru)
30	0.18	240	100	0.06	247
130	0.24	274	200	0.30	298
230	0.12	306	300	0.36	338
330	0.42	18	400	0.71	33
430	0.71	45	500	0.71	45
530	0.24	58	600	0.18	69
630	0.06	106	700	0.12	137
730	0.06	153	800	0.24	159
830	0.48	166	900	0.30	172
930	0.24	174	1000	0.30	206
1030	0.24	226	1100	0.30	239
1130	0.30	245	1200	0.24	239
1230	0.24	246	1300	0.24	267
1330	0.18	249	1400	0.06	231
1430	0.06	230	1500	0.06	242
1530	0.18	19	1600	0.24	25
1630	0.60	53	1700	0.77	72
1730	0.60	52	1800	0.18	36
1830	0.06	106	1900	0.18	131
1930	0.18	196	2000	0.30	195
2030	0.30	159	2100	0.42	158
2130	0.36	181	2200	0.36	207
2230	0.36	223	2300	0.36	237
2330	0.36	241	2400	0.36	266

APPENDIX B

CLINTON HARBOR STATION LOCATIONS

<u>Station Descriptions - Clinton Harbor</u>

<u>September 2, 1981</u>

Station descriptions will be done in the following format:
 Station
 Depth
 Time of Sampling
 Compass Bearings or Range to Markers
 Comments

STATION 1

 18'
 7:30 AM
 55° - 60° — Kelsey Point
 322° - 325° -- Tank
 <u>Ensis</u> and Maldanids, marsh plant detritus; dark anaerobic mud with thin redox

STATION 2

 15'
 7:45 AM
 140 yards west of Bell #1
 Anaerobic mud, thin redox, small <u>Yoldia</u>

STATION 3

 14'
 8:10 AM
 140 yards west of N "2"
 Muddy sand, <u>Nephtys</u>, Maldanids

STATION 4

 13'
 8:40 AM
 400 yards from north end of Kelsey Pt. Breakwater
 340° - Hammock Pt.
 Mud, plant detritus, <u>Nephtys</u>, <u>Yoldia</u>

STATION 5

 13'
 9:10 AM
 Line up West Rock with Tank
 Sand/mud; <u>Ensis</u>, Maldanids

STATION 6

 10'
 10:10 AM
 110 yards NW of Wheeler Rock, Can #3

STATION 7

 10'
 9:50 AM
 120 yards of Nun "4", line up Nun "4" with Tank

STATION 8

   7'
   10:45 AM
   110 yards west of Can "9" (note: Can 9 not charted)
   Sandy mud

STATION 9

   6'
   12:30 PM
   280° - Tank
   190° - West Rock
   140 yards east of shore

STATION 10

   6'
   1:00 PM
   115° to Wheeler Rock
   300° to Tank
   160° to West Rock
   Line up Wheeler Rock on north end of Kelsey Pt. Breakwater

STATION 11

   7'
   1:20 PM
   300° - Tank
   100° - Kelsey Pt.
   205° - Eastside of Hammock Point
   375 yards east of beach

STATION 12

   6'
   2:00 PM
   175 yards east of Nun "8"
   270° - Nun "8"
   145° - Hammock Point

STATION 13

   7'
   2:20 PM
   At mooring pile next to last house toward west
   84 yards off beach

STATION 14

   6'
   2:35 PM
   Midway between Nuns 10 and 12, just south of Hammock River channel marker
    posts
   Eel grass bed

<u>September 3, 1981</u>

STATION 15

    5.5'
    285° - Tank
    90° - Can #7
    217° - West Rock
    105° - Hammock Point
    120 yards west of Can #7

STATION 16

    8'
    11:40 AM
    302° - Tank
    225° - East side Hammonasset Point
    102° - Hammock Point
    325 yards west of Wheeler Rock

APPENDIX C

CLINTON HARBOR INFAUNAL RAW DATA
(ALL COUNTS PER 0.04 m^2)

CRITERIA \ SITE	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B	7A	7B	8A	8B	9A	9B	10A	10B	11A	11B	12A	12B	13A	13B	14A	14B	15A	15B	16A	16B
Bivalves																																
Tellina agilis	5			2	2		6	5	8	2	2		2	5	14	7	4	4	1	12	20	21	4	4	4	9	9	14	2	6	25	29
Mulinia lateralis	3		5	4	1		5	4	4	9	11		4	4																1	1	5
Gemma gemma																			2	4	17	3	5	8		1	7		8	2	1	3
Nucula proxima	2						1					1																1				
Ensis directus	7							1	4																		1				1	
Lyonsia hyalina										1																						
Yoldia limatula	2	3																														
Pandora gouldiana	1									1																						1
Spisula solidissima																																
Bivalvia unident.																	1											1				
Aequipecten irradians																																
Anadara transversa																																
Nucula delphinodonta																																
Thracia septentrionalis(?)																												1				
Tellina sp.																																
Mya arenaria																																
Mytilus edulis																												1				
Amphipods																																
Unciola irrorata																																
Listriella barnardi															5		4	2	4									11				
Ampelisca abdita	5	1		1	1				1		1	1																		2		
Trichophoxus epistomus																													5	11	1	
Paraphoxus spinosus															1	49												1				
Melita nitida																2												3				
Caprellidae																																
Protohaustorius deichmannae																													2	7		
Photis reinhardi																																
Ericthonius brasiliensis																																
Caprella penantis																																
Ampelisca agassizi																														2		
Acanthohaustorius millsi																3												4				
Elasmopus levis																																1
Aeginina longicornis																																
Unciola sp.																7																
Unciola serrata																																
Monoculodes sp.																		3														
Jassa falcata																														2		
Amphipoda unident.																														2		
Amphithoe valida															2							1						14	23			
Corophium bonelli																																
Gastropods																																
Nassarius trivittatus			4		2			1																							1	2
Crepidula fornicata															1	31												2				
Ilyanassa obsoleta																					5				5	110	8					
Crepidula plana																11																

September

CRITERIA / SITE	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B	7A	7B	8A	8B	9A	9B	10A	10B	11A	11B	12A	12B	13A	13B	14A	14B	15A	15B	16A	16B
Turbonilla sp.																																
Acteocina canaliculata																																
Edotea triloba		1		1																												
Mitrella lunata																											2	3				
Gastropoda unident.																																
Cylichna oryza																																
Crepidula convexa																											8	3				
Lacuna vincta																									1			2				
Odostomia bisuturalis																											1	3				
Crepidula sp. (juv.)															1																	
Bittium alternatum																												1				
Alvania areolata																																
Corambella sp.																																
Odostomia sp.																																
Turbonilla elegantula																											1					
Crustacea																																
Pagurus longicarpus				1						1		1		1	3	2												3				
Oxyurostylis smithi	1																1				1		1									
Cytheridea americana																																
Cirripedia																																
Neopanope sayi	1																										2	2				
Ovalipes ocellatus																																1
Crangon septemspinosa														1				1			1											
Heteromysis formosa																8																
Idotea balthica																												1	1			
Leptochelia savignyi																														3		
Upogebia affinis				1										1		2																
Cylindroleberis mariae																																
Hutchinsonella macracantha							1	1																				5				
Balanus improvisus																																
Idotea phosphorea																																
Sarsiella sp.																																
Pinnixa sp.																																
Cancer irrorutus									1																							
Leucon americanus																																
Chiridotea tuftsi																																
Neomysis americana																																
Palaemonetes vulgaris																													1			
Hippolyte zostericola																																
Annelida																																
Streblospio benedicti	9	16	28	12	27	13	30	18	67	21	60	86	87	47	93	3	11	22	48	14	12	16	3		72	37	219	248	1		12	27
Tharyx acutus	3	3		1	1	2			8		15	6	34	50	8	46	2	1	11	4	3	3				1	4	7		1	12	19
Glycera americana	1	1		2			7	5				1	5	4	3	2	1	1	8	4	1	1		1	1	3	3	1		5	7	6
Mediomastus ambiseta	29	26	5	36	377	177	252	340	78	12	10	38	49	15	31	18		3	8				2		4	18	291	207				6
Oligochaeta	4	3					23	1		2			2		4	36			1	1	3	1	3	1	15	12	142	229	4			6
Spiophanes bombyx									10	1			1	1	1				2		1	2	2						4	2	8	16
Nephtys picta				1								1																			2	

C-2

September

CRITERIA / SITE	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B	7A	7B	8A	8B	9A	9B	10A	10B	11A	11B	12A	12B	13A	13B	14A	14B	15A	15B	16A	16B
Scoloplos acutus				1					1		1	1					2	1	1	2	1	4	1			2		1		1	1	3
Syllinae/Eusyllinae															6		1	2			4	3								1	4	3
Paraonis fulgens	1																100	124	42	68	10	6	10	7	30	18			1		4	21
Aricidea sp.									8	4		1		1	3			1	1								1	1			15	36
Polygordius spp.				1					2						3			1														
Anaitides spp.									1																		2	1				
Pectinaria gouldii				1					1						3	1											4	6	1			
Exogone sp.												1																				
Asabellides oculata	1																															
Nephtys incisa	8	2	14	56	1		26	20				1			3		28	54				1					1				1	
Scolecolepides viridis																12											1	6	1			
Eumida sanguinea															1																	
Polydora socialis												1		2	1	1											11	5				
Clymenella torquata				1				1	1						1								1				1				1	
Capitella capitata																																
Eteone heteropoda																											16	10	1			
Lumbrineris sp.		1																														
Magelona rosea															2													1				
Nereis sp.																																
Sabellaria vulgaris																		1														
Harmothoe imbricata																																
Lepidonotus squamatus															1												4					
Polydora ligni																																
Hydroides dianthus																																
Maldanidae unident.																																
Dorvilleidae unident.																												1				
Cossura longocirrata																																
Anaitides arenae																										50						
Scoloplos squamata																											6					
Phyllodocidae unident.																													1			
Polychaeta unident.																													1			
Schistomeringos caecus																																
Nereis zonata																											2					
Scoloplos robustus																																
Paranaitis speciosa																																
Spiochaetopterus oculatus	1																															
Spio filicornis																		1									1					
Nereis grayi																									1							
Polycirrus sp.																												1				
Pista palmata / Eulalia viridis																							1									
Drilonereis longa / Nereis arenaceodonta				1																												
Sigambra tentaculata				1																												
Owenia fusiformis / Glycera sp.					2																											
Polydora sp.																																
Glycera dibranchiata																																
Polydora commensalis																																

C-3

September

CRITERIA \ SITE	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B	7A	7B	8A	8B	9A	9B	10A	10B	11A	11B	12A	12B	13A	13B	14A	14B	15A	15B	16A	16B
Misc.																																
Tubulanus pellucidus																																
Nemertea unident.	1	1			1			1			1											1					1		3	2	1	3
Turbellaria																																
Phoronida																																
Euplana gracilis																		1														
Holothuroidea																																
Ophiuroidea								2																								

C-4

October

CRITERIA \ SITE	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B	7A	7B	8A	8B	9A	9B	10A	10B	11A	11B	12A	12B	13A	13B	14A	14B	15A	15B	16A	16B
Bivalves																																
Tellina agilis	263	206	164	20	69	100	11	9	185	136	74	50	80	93	7	6	18	16	22	14	43	33	11	13	2	1	20	17	24	24	37	1
Mulinia lateralis	6	12	645	14	113	80	85	91	39	17	2	1	15	23						1	5										4	4
Gemma gemma															5		60	45	72	105	7	15	6	15	6					5	8	4
Nucula proxima			3		1	1	7	2	1														1						1			
Ensis directus	1									1											2	3										
Lyonsia hyalina	3	1				2																										1
Yoldia limatula			1				1	2			2																					
Pandora gouldiana	1					1														1									2		1	
Spisula solidissima		2																													2	
Bivalvia unident.																								1						1		
Aequipecten irradians																																
Anadara transversa																											1					
Nucula delphinodonta	1																															
Thracia septentrionalis(?)																		5														
Tellina sp.																																
Mya arenaria																		1														
Mytilus edulis																																
Amphipods																																
Unciola irrorata	4	2		1						3		1	2	1		1					4	5					1					
Listriella barnardi															1		1	7	5			1	7	2					2			
Ampelisca abdita			1																			1								6		
Trichophoxus epistomus													1		6				1			1										
Paraphoxus spinosus																	68					1							5	4		
Melita nitida																	9					1		1				1			2	
Caprellidae																						1			1			1		1	23	
Protohaustorius deichmannae																					8	4					1					
Photis reinhardi																8	1					4										
Ericthonius brasiliensis																6							1	1								
Caprella penantis			2			1				1																						
Ampelisca agassizi																																
Acanthohaustorius millsi																																
Elasmopus levis																					1											
Aeginina longicornis																		1														
Unciola sp.																																
Unciola serrata																													1			
Monoculodes sp.																																
Jassa falcata																																
Amphipoda unident.																																
Amphithoe valida															1	9	3				1						4	9				
Corophium bonelli																																
Gastropods																																
Nassarius trivittatus	4	6	3		3	1	1		3	2					3	36													1			
Crepidula fornicata																46	4					1	5	5	1				10	3	1	
Ilyanassa obsoleta		1								1									2	5					16	1	1		12	2		
Crepidula plana															11	54	4				8	11							1			3

October

CRITERIA / SITE	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B	7A	7B	8A	8B	9A	9B	10A	10B	11A	11B	12A	12B	13A	13B	14A	14B	15A	15B	16A	16B
Turbonilla sp.									1		7	5	1	2	3														1			
Acteocina canaliculata			1		1	1		2		2		1																		1		
Edotea triloba																																
Mitrella lunata						3									3	14													10			
Gastropoda unident.												1	1									1					1			2		
Cylichna oryza			3		3		1	1					2																			
Crepidula convexa																																
Lacuna vincta																																
Odostomia bisuturalis																																
Crepidula sp. (juv.)													1																			
Bittium alternatum																																
Alvania areolata									1																							
Corambella sp.										1																						
Odostomia sp.											1																					
Turbonilla elegantula																																
Crustacea																																
Pagurus longicarpus	1	1						1		3		3			3	23	32		2	2	15	18					8					2
Oxyurostylis smithi	1								3	2	1						3								4	1						
Cytheridea americana												1	2	2			6	6			1		33	104	2	2					14	1
Cirripedia				1		1		1		8					2	31	6					2	63	8	23		4					
Neopanope sayi																	7															
Ovalipes ocellatus																		1		1					1							
Crangon septemspinosa																5						1										
Heteromysis formosa																											2					
Idotea balthica													1																	2		
Leptochelia savignyi																																
Upogebia affinis																											1					
Cylindroleberis mariae																																
Hutchinsonella macracantha																																
Balanus improvisus																												1				
Idotea phosphorea																											1					
Sarsiella sp.		1																														
Pinnixa sp.																								1								
Cancer irrorutus																															1	
Leucon americanus																																
Chiridotea tuftsi																	1															
Neomysis americana										1																						
Palaemonetes vulgaris																																
Hippolyte zostericola																											1					
Annelida																																
Streblospio benedicti	36	2	478	33	124	146	42	34	393	935	667	741	170	413	25	3	332	161	299	182	361	153	1		91	75	168	218	3		50	71
Tharyx acutus	5	9	3	1				1	7	24	11	11	21	42	2	1	6	1	34	19	1	1			1		8	8	3	3	16	8
Glycera americana	7	2	5	2	5				5	6	10	8	2	1		2	4	2	2	3	18	10			1	7	2	8	4	1	2	4
Mediomastus ambiseta	39	39	36	6	213	104	36	6	11	28	18	26	2	62	1		28	25	11	26	4	1		1	12	4	180	169	1			
Oligochaeta				1			9	5									210	199	141	212	178	25	4	7	10	5	249	111	8		5	1
Spiophanes bombyx	38	121	3		7	4			16	13	18	11	18	44			2				1	1		1		2	1		5	1	69	67
Nephtys picta	105	113	93	14	24	47		2	33	45	45	15	4	38	3		1		1	3	3	4	3	2	1		1	1	13	8	29	51

October

CRITERIA / SITE	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B	7A	7B	8A	8B	9A	9B	10A	10B	11A	11B	12A	12B	13A	13B	14A	14B	15A	15B	16A	16B
Scoloplos acutus	2		1		2	1			1	2	1				1		1				4		1		1	2	7	6	1			
Syllinae/Eusyllinae									1					1	12	5	83	27	40	21	10	12	3	12	31	5	2	1	19	2	1	14
Paraonis fulgens																25		8	2	5	2			1	92	19					15	16
Aricidea sp.	3	16	1		1		1		12	18	1			3			3														2	3
Polygordius spp.	23								1	3							6												13		22	13
Anaitides spp.	2							1					2	7			26			1		1	1		2	1	5					
Pectinaria gouldii			1		1	3				3	1					1	1										2	1				
Exogone sp.																		3	2	5	2	3			1	1	15	8	2			
Asabellides oculata	2				3	3	1	3	2	5			2	14								2					1					
Nephtys incisa		14			6		21	10			1							5							1	3	2				2	
Scolecolepides viridis																		5						2	1	3	2				2	
Eumida sanguinea																											6	4				
Polydora socialis	1		2									1			3			3			1											
Clymenella torquata																																
Capitella capitata																					4						5	2				
Eteone heteropoda						1					1							2	12	7	6						7					
Lumbrineris sp.											1																13	6	1		1	
Magelona rosea			3														2										1					
Nereis sp.																																
Sabellaria vulgaris																582						1	33	30								
Harmophoe imbricata																1											1					
Lepidonotus squamatus																1		1				1										
Polydora ligni																												7				
Hydroides dianthus																15											10					
Maldanidae unident.																											27	2				
Dorvilleidae unident.																																
Cossura longocirrata			1																								1					
Anaitides arenae										6																						
Scoloplos squamata																	16															
Phyllodocidae unident.																																
Polychaeta unident.																													1			
Schistomeringos caecus																																
Nereis zonata																																
Scoloplos robustus																52																
Paranaitis speciosa																																
Spiochaetopterus oculatus																																
Spio filicornis																																
Nereis grayi																																
Polycirrus sp.																																
Pista palmata																																
Eulalia viridis																1																
Drilonereis longa																																
Nereis arenaceodonta																																
Sigambra tentaculata																																
Owenia fusiformis									1																							
Glycera sp.																	2															
Polydora sp.																													11			
Glycera dibranchiata																															3	
Polydora commensalis																																

October

CRITERIA \ SITE	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B	7A	7B	8A	8B	9A	9B	10A	10B	11A	11B	12A	12B	13A	13B	14A	14B	15A	15B	16A	16B
Misc.																																
Tubulanus pellucidus	4	1	13		3	6	10	8			4	2	1			1	1					3								1	1	
Nemertea unident.									1	5				1		4		1					15	45			4					
Turbellaria														1		1											2					
Phoronida	1									1																	1					
Euplana gracilis																																
Holothuroidea																																
Ophiuroidea													1																			

C-8

APPENDIX D

SEDIMENT PROFILE PHOTOGRAPHY
DATA SUMMARY

Date: September 1981

D-1

Station #	Modal Grain Size	Penetration Depth (cm)	Ripple Index	RPD (cm^2) Area	Grain Size Used in Shield's Calc.	Minimum u_*	τ_o	Successional Stage	Habitat Index
1	fs,fs-ms,fs(surface) silt(subsurface)	5.33,5.08,4.03	none	40.32,39.13,27.1	125μ	1.21 cm/s	1.46 dynes/cm^2	I4,I,I	+5
2	vfs-silt,vfs-silt, vfs	2.68,3.45,1.77	none	24.1,46.05,?	~62	1.10	1.20	I,I,I	+5
3	vfs,vfs-fs,vfs-fs	0.49,0.29,0.59	none		125			I?,I?,?	
4	-	-		-	-	-	-		
5	fs,fs,fs	1.84,0.53,1.93	yes		125	1.21	1.46	I,?	
6	vfs-fs,vfs-fs, vfs-fs	4.45,2.31,3.11	none	26.9,14.46,14.5	62-125	1.10-1.21	1.20-1.46	I/infauna,I/inf,I	+3
7	vfs,?,?	0.33,0,0	none		62-125	1.10-1.21	1.20-1.46		
8	ms,ms	1.03,0,1.41	none		250	1.32	1.74	C. fornicata	
9	ms,ms,ms	1.22,0.70,1.21	19,9,13.3		250	1.32	1.74	I,?,I poorly developed/stress-tolerant infauna	
10	fs,fs,fs	0.57,0.71,0.77	6.9,9.0,5.5		125	1.21	1.46	maldanids(?)	
11	fs,fs,ms	1.83,1.67,1.63	<6.5,10,<7.5		125-250	1.21-1.32	1.46-1.74		
12	fs,fs,fs	0.83,1.66,0.71	28,76.5,13		125	1.21	1.46		
13	fs,fs,vfs-fs	1.35,1.22,1.21	none (biogenic)		62-125	1.10-1.21	1.20-1.46	infauna conveyor-belt species (maldanids?)	
14	silt-vfs	2.56,2.29,2.18	none		62-125	1.10-1.21	1.20-1.46	Zostera	
15	ms,ms,ms	1.21,2.75,1.35	24,7.5,5.9		250-500	1.32-1.61	1.74-2.59		
16	ms,ms,fs-vfs	0.50,0.59,1.49	-,-,15		125-250	1.21-1.32	1.46-1.74	maldanids?, bivalves?,	
Transect:									
1	ms,fs-ms	0.62,0.50	10,19		125-250	1.21-1.32	1.46-1.74		
2	cs,cs	1.04,1.07	yes		500-1000	1.61-2.31	2.59-5.34	Zostera	
3	-,fs	-,2-32	yes		125-250	1.21-1.32	1.46-1.74		
4	cs,cs	1.21,0.96	none		500-1000	1.61-2.31	2.59-5.34	conveyor-belt polychaete	
5	cs,vcs	1.37,1.01	none		500-1000	1.61-2.31	2.59-5.34	Zostera	
6	?,?		none		-	-	-	C. fornicata	

Date: October 1981

Station #	Modal Grain Size	Penetration Depth (cm)	Ripple Index	RPD (cm^2) Area	Grain Size Used in Shield's Calc.	Minimum u_*	τ_o	Successional Stage	Habitat Index
1	ms,ms,ms	0.88,0.68,1.12	yes		250μ	1.32 cm/s	1.74 dynes/cm^2	I,?,?	
2	vfs,silt,silt	2.88,2.96,2.10	none	-,35.01,27.31	62-125	1.10-1.21	1.20-1.46	I,I,I	+5
3	fs,?,?	0.49,0,nil	yes		125	1.21	1.46	I,I	
4	silt,silt,silt	6.78,5.37,5.02	none	25.7,29.32,13.86	62	1.10	1.20	I,I,I	+4
5	ms,fs,fs	1.66,0.84,0.53	-,14,14		125-250	1.21-1.32	1.46-1.74	I,I,I	
6	fs,fs,fs	2.10,0.76,2.40	-,18,-,		125	1.21	1.46	I,I,I	
7	vfs,vfs,vfs	0.26,0.40,0.31	14,?,18		62-125	1.10-1.21	1.20-1.46		
8	?silt+ms,silt+ms	0,1.51,0	none		250	1.32	1.74	C. fornicata	
9	ms,ms,ms	1.32,0.65,0.90	-,-,7.3		250	1.32	1.74		
10	fs,ms,vfs	1.06,0.81,0.42	-,14		125	1.21	1.46	conveyor-belt	
11	cs-vcs,cs,cs-vcs	1.01,1.50,0.83	-,8,9		500	1.61	2.59	epifaunal herbivores	
12	fs,fs,fs	1.03,1.12,0.96	-,-,>10		125	1.21	1.46	mobile infauna	
13	fs,fs,fs	0.88,0.94,0.94	11.5,22,9.2		125	1.21	1.46	conveyor-belt feeders	
14	vfs,vfs,vfs	1.43,1.32,2.0	none		62	1.10	1.20	Zostera,Zostera,Zostera	
15	fs,fs,fs	1.78,1.43,1.73	10,8.3,8.7		125	1.21	1.46		
16	fs-ms	1.46,1.84,2.07	7.0,6.0,2.0		250	1.32	1.74	?	

Transect:

1	vfs,fs	0.63,1.33	yes		62-125	1.10-1.21	1.20-1.46	stress-tolerant mobile infauna	
2	fs,fs	1.28,1.96	11		125	1.21	1.46	stress-tolerant mobile infauna	
3	ms,ms	2.02,2.57	yes		250	1.32	1.74		
4	ms,ms	1.28,0.65	yes		250	1.32	1.74		
5	ms,cs	1.11,1.88	18,-		250-500	1.32-1.61	1.74-2.59		
6	cs	nil	no		500	1.61	2.59		

Report to

Department of the Army
New England Division
CORPS OF ENGINEERS

Benthic Algae and Fauna of Clinton Harbor, CT
June, 1982

Taxon, Inc.
50 Grove St.
Salem, MA 01970

Report to

Department of the Army
New England Division
CORPS OF ENGINEERS

on

Amendment No. 1 to
Contract DACW 33-81-C-0116

Mr. G. L. Chase
Contract Monitor
Impact Analysis Branch

Environmental Baseline Data Collections and Site Evaluations
Long Island Sound Container Disposal Study

Benthic Algae and Fauna of Clinton Harbor, CT
June, 1982

Richard A. McGrath
Walter F. Grocki

August 1982

Taxon, Inc.
50 Grove St.
Salem, MA 01970

1.0. INTRODUCTION

This document presents the results of an environmental survey of soft and hard bottom benthic communities performed under Amendment No. 1 to Contract No. DACW33-81-C-0116 to Taxon, Inc. This work is a continuation of a multi-disciplinary environmental baseline data collection and site evaluation performed in September - October, 1981 (McGrath, et al., 1982).

The purpose of the present study was to document existing conditions in the benthic infaunal communities of the proposed container disposal area during the spring season; all three previous inventories in this area (Pellegrino and Baker, 1975(?); McGrath, et al., 1978; McGrath, et al., 1982) were conducted in the Fall. It was felt that some additional sampling was necessary to assess seasonal variation in the composition of the fauna.

In addition, a sampling of local hard (rock) bottom algae and fauna was included in order to evaluate the type of community which will develop on the outer face of the rock containment structure as it is presently proposed (Garbisch, 1982). Littoral hard-bottom communities have been shown to be both more dense and diverse than infaunal communities in the same area and it is believed that this will ameliorate, to some degree, the removal from the Clinton Harbor system of a large area of soft bottom habitat due to emplacement of the disposal area.

2.0. METHODS

Sampling for this phase of the Clinton Harbor Baseline Data Collection and Site Evaluation was conducted on 3 June 1982. All sampling was performed in accordance with the provisions of Job Change No. 1 to Contract DACW33-81-C-0116.

2.1. Field

Nine of the 16 stations occupied during September and October, 1981 were selected for resampling during the spring of 1982 (Figure 1). Two replicate $0.04m^2$ samples were collected at each station with a modified Van Veen grab, placed in muslin bags, and preserved in drums of buffered 10% seawater formalin. Station locations were established via ranges and azimuths on fixed landmarks and distance measurements using a parallax-type rangefinder. Complete station locations are provided by McGrath (1982).
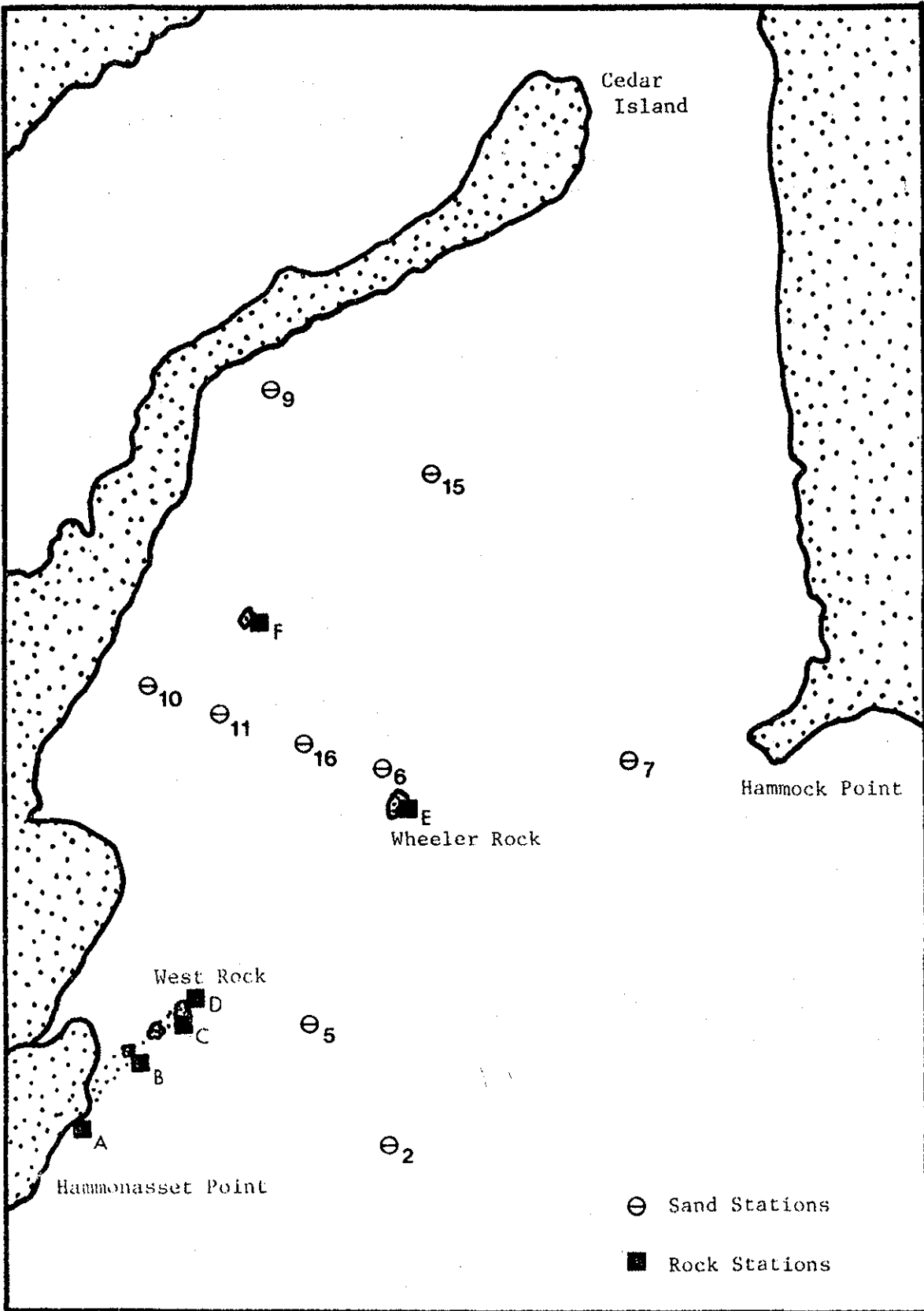
Figure 1: June, 1982 sampling locations.

At each of the six rock stations (Figure 1), two replicate $0.1m^2$ samples were collected by divers using the air-lift collection device shown in Figure 2. A $33cm^2$ pipe-frame quadrat was placed on the rock and all algal and faunal material within the quadrat was scraped off the rock surface and suctioned into a 0.5mm nylon mesh collection bag attached to the air-lift. Upon return to the surface, the nylon bags were sealed and preserved in drums of buffered 10% seawater formalin.

We attempted to restrict the elevation of the rock substratum samples to the area immediately below the zone which is exclusively barnacles, or to approximately -.5m (MLW). This was not possible in the case of Station E (Wheeler Rock) which is entirely below this elevation or Station F, which is entirely above it. Although this variation tends to make strict comparisons between the rock stations more difficult, it does simulate, to some extent, the range of habitats to be expected on the proposed containment breakwater.

2.2. Laboratory

All samples were returned to and analyzed at our laboratory in Salem, Massachusetts. Following fixation in formalin for 48 hours, the grab samples were sieved through 0.5mm stainless-steel sieves and stored in 70% isopropanol. Rock substratum samples were washed and the algal and faunal material separated by eye in enameled basins. Faunal material was stored in 70% isopropanol and subsequently treated in the same manner as the grab samples. Algal material was maintained in a 5% formalin solution prior to processing.

Faunal samples were analyzed via a two-step procedure (presorting, separation of fauna from residual material and final sorting, identification and enumeration of the component fauna); identifications were made at the species level whenever the condition of the specimen and current taxonomic practices permitted. Algal material was identified to species when possible. Algal biomass for each species was determined by drying the algal material at 70°C for 48 hrs. and weighing on a top-loading analytical balance.
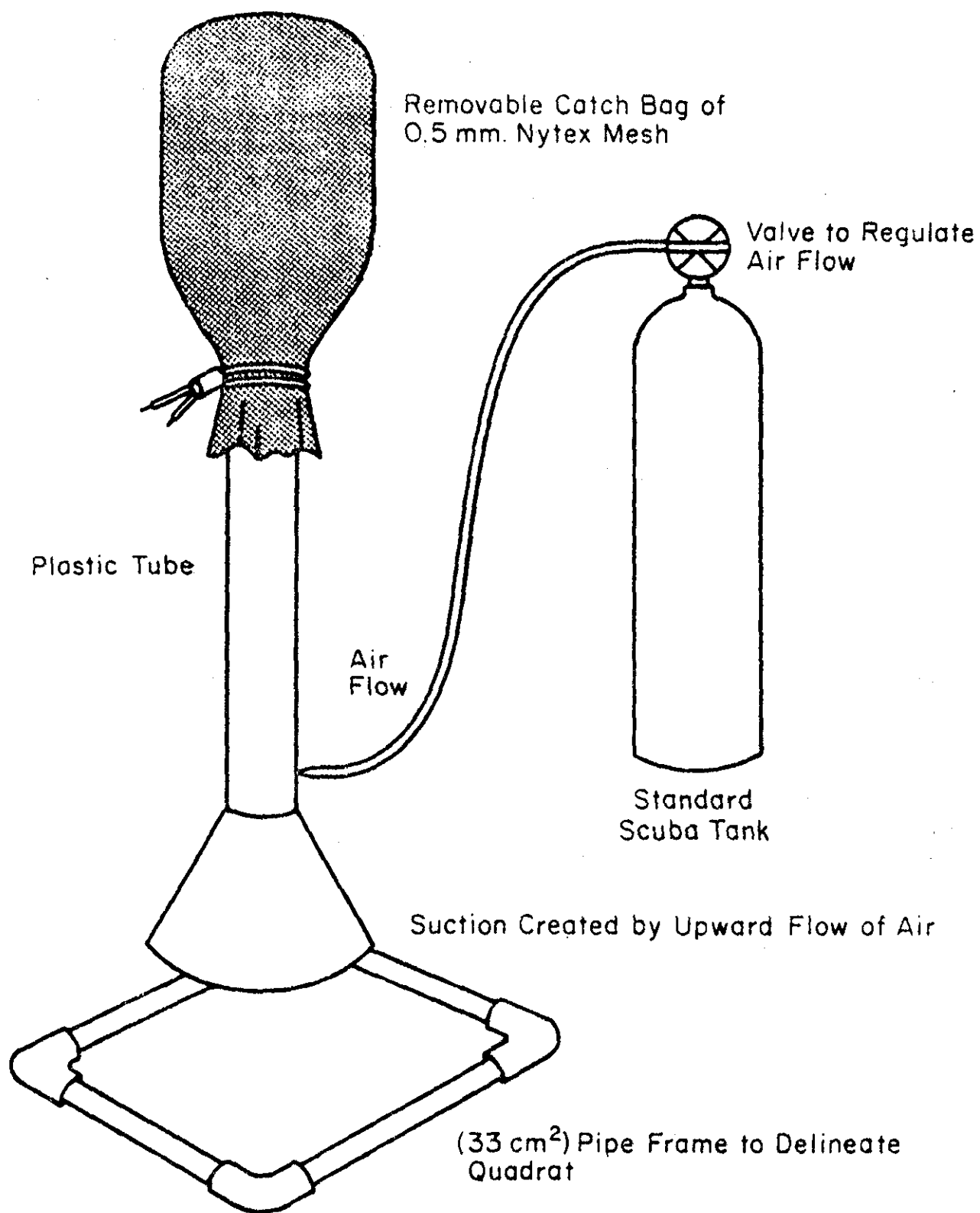
Removable Catch Bag of
0.5 mm. Nytex Mesh

Valve to Regulate
Air Flow

Plastic Tube

Air
Flow

Standard
Scuba Tank

Suction Created by Upward Flow of Air

(33 cm^2) Pipe Frame to Delineate
Quadrat

FIGURE 1. Rock substratum airlift sampling device.

2.3. Data Analysis

Faunal data was entered into the Woods Hole Oceanographic Institution's VAX/11-780 computer and analyzed using a suite of programs originated at WHOI specifically for benthic faunal data. These included PRARE1 (diversity calculations and data listing), PERSORT (abundance rankings), and SPSTCL (classification analysis).

Diversities were calculated using the Shannon-Wiener formula:

$$H' = -\sum p_i \ln p_i,$$

where p_i is the proportion of the ith species in the sample. The similarity coeffient used for the classification analysis was the Bray-Curtis similarity index:

$$\sum_{AB} MIN \left[\frac{N_i^A}{N^A} , \frac{N_i^B}{N^B} \right]$$

which is calculated as the sum, over all species in common between two samples, of the smaller of the two percentages at which the species occurs in the two samples. The clustering strategy selected was unweighted pair-group using arithmetic averages (UPGMA). Both methods have seen wide application in ecological studies (Boesch, 1977).

3.0. RESULTS

3.1. The Sand Substratum Fauna

The spring benthic faunal communities show marked similarity to those described from the Fall, 1981 collections but there are also some obvious differences due to a combination of seasonal (or longer-term) variation and random variation inherent in natural populations. A complete taxonomic list of the species and/or taxa collected in June at Clinton Harbor is presented in Table 1. Of the 90 species found at the sand stations, nearly all were also present in previous collections (McGrath, et al., 1982).

The most obvious changes in the sand fauna between the two seasons are in the dominance patterns. In September - October 1981, the polychaete Streblospio benedicti was the most common infaunal species in the study area; in the recent collection, Streblospio was present in less than 75%

Table 1: Species list from June, 1982 sampling of Clinton Harbor. Species within each taxonomic group are arranged in approximate order of abundance.

MOLLUSCA

Tellina agilis
Mytilis edulis
Gemma gemma
Lacuna vincta
Mitrella lunata
Nassarius trivittatus
Crepidula fornicata
Littorina littorea
Petricola pholadiformis
Urosalpinx cinerea
Anachis translirata
Crepidula plana
Mulinia lateralis
Onchidoris aspera
Bittium alternatum
Hiatella arctica
Nucula annulata
Anomia simplex
Nucula delphinodonta
Anomia aculeata
Turbonilla elegantula
Lunatia sp.
Spisula solidissima
Margarites umbilicalis
Anadara transversa
Gastropoda
Ilyanassa obsoleta
Odostomia gibbosa
Turbonilla nivea

ECHINODERMATA

Amphipholis squamata

MISCELLANEOUS

Nemertea
Metridium senile
Turbellaria
Euplana gracilis
Sipunculoidea

CRUSTACEA

Jassa falcata
Corophium bonelli
Corophium acutum
Marinogammarus stoerensis
Calliopius laevisculus
Balanus improvisus
Caprella penantis
Neopanope sayi
Aeginina longicornis
Erichsonella filiformis
Erichthonius brasiliensis
Idotea balthica
Ostracoda
Pagurus longicarpus
Leucon americanus
Idotea phosphorea
Unciola serrata
Edotea triloba
Leptochelia savignyi
Corophium simile
Paraphoxus spinosus
Trichophoxus epistomus
Oxyurostylis smithi
Cancer irroratus
Elasmopus levis
Phoxichilidium femoratum
Gammarus oceanicus
Cyathura polita
Phoxocephalus holbolli
Monoculodes edwardsi
Caprellidae
Decapoda
Jaera marina
Pseudoleptocuma minor
Libinia dubia
Tanystylum orbiculare
Photis sp.
Stenothoe minuta
Ampelisca abdita
Cumacea
Proboloides holmesi

6

Table 1 (cont.)

ANNELIDA

Scolecolepides viridis
Tharyx acutus
Oligochaeta
Asabellides oculata
Harmothoe imbricata
Streblospio benedicti
Glycera americana
Mediomastus ambiseta
Syllinae/Eusyllinae
Prionospio steenstrupi
Polygordius spp.
Exogone sp.
Autolytus sp.
Polydora aggregata
Sabellaria vulgaris
Nereis pelagica
Spiophanes bombyx
Autolytus cornutus
Paraonis fulgens
Fabricia sabella
Marphysa sanguinea
Odontosyllis sp.
Aricidea catharinae
Nephtys picta
Phyllodocidae
Eteone heteropoda
Polycirrus eximius
Nephtys incisa
Nephtydae
Potamilla reniformis
Anaitides groenlandica
Orbiniidae
Pista palmata
Autolytus fasciatus
Maldanidae
Sabella microphthalma

Archiannelida
Capitella capitata
Polydora ligni
Eumida sanguinea
Parapionosyllis longicirrata
Eteone lactea
Nicolea venustula
Nereis sp.
Clymenella torquata
Pygospio elegans
Pholoe minuta
Polydora commensalis
Lepidonotus squamatus
Ampharetidae
Nereidae
Aricidea cerruti
Polychaeta unid.
Cirratulidae
Hydroides dianthus
Drilonereis longa
Spionidae
Dodecaceria corali
Capitellidae
Peloscolex benedeni
Sphaerodoropsis minuta
Potamilla sp.
Nereis zonata
Sigalionidae
Hesionidae
Scoloplos acutus
Dorvilleidae
Cirratulus grandis
Anaitides mucosa
Polydora caulleryi
Nereis arenaceodonta
Spio filicornis

of the samples (Table 2). Conversely, a suite of amphipod species (Jassa falcata, Corophium acutum and C. bonelli, and Marinogammarus stoerensis) which were present as dominants in the recent collection, appear infrequently in the earlier study. Some species, including the bivalve Tellina agilis, the polychaete Tharyx acutus, and the Oligochaetes were dominants in both collections and can probably be regarded as the more stable and continuous faunal species in the harbor.

Species richness among the sand substratum stations (Table 3) varied from a low of 13 taxa at Station 7-2 to a high of 30 taxa at Station 16-1 ($\bar{x}$ = 19.9 species/0.04m^2). These values were generally higher than those from the Fall collections, probably due to an influx of transient species from planktonic dispersal of the larvae of spring-spawning benthic species.

Faunal densities (Table 3), extrapolated to numbers of individuals per square meter, varied from 1500/m^2 to 35,650/m^2 ($\bar{x}$ = 8,968/m^2). These values are generally higher than those from the September – October collections and are again probably indicative of the effect of spring-spawning species.

Shannon-Wiener diversity values (H') (Table 3) were also generally higher and somewhat more stable throughout the area in the recent collections, particularly in comparison with the data from September, 1981. The mean diversity value (2.71) is essentially equal to that recorded in October, 1981 (2.70).

3.2. The Rock Substratum Fauna

One of the purposes of the present study was to document the characteristics of the resident hard-bottom benthos in the harbor in order to develop an understanding of the type of community which would be expected to develop on the proposed containment breakwater. The data indicate that such a community would be richer in both density and diversity than the present soft-bottom community, and would share many of the same species.

The dominant species in the rock substratum benthic community were generally of three types: (1) species which attach to the substratum and are absolutely restricted to hard bottom; (2) species which depend upon attached macro- and micro-algae as a food source and are more-or-less

Table 2: Most commonly occurring species at rock and sand stations.

Sand Substratum		Rock Substratum	
Species	% Occurrence	Species	% Occurrence
Tellina agilis	100.0	Jassa falcata	100.0
Jassa falcata	100.0	Corophium acutum	100.0
Tharyx acutus	88.9	Mytilis edulis	100.0
Scolecolepides viridis	83.3	Lacuna vincta	100.0
Corophium acutum	77.8	Corophium bonelli	100.0
Corophium bonelli	77.8	Harmothoe imbricata	91.7
Streblospio benedicti	72.2	Calliopius laevisculus	83.3
Gemma gemma	72.2	Balanus improvisus	83.3
Oligochaeta	61.1	Marinogammarus stoerensis	75.0
Marinogammarus stoerensis	61.1	Mitrella lunata	75.0
Asabellides oculata	55.6	Caprella penantis	58.3
Glycera americana	55.6	Neopanope sayi	58.3
Mediomastus ambiseta	55.6	Nereis pelagica	58.3
		Polydora aggregata	58.3

Table 3: Species richness, faunal density, and diversity by replicate for June, 1982 Clinton Harbor sampling.

Sample	# Species	# Individuals	#/m^2	Diversity
2-1	15	60	1500	3.29
2-2	19	71	1775	3.73
5-1	18	314	7850	2.50
5-2	17	184	4600	2.62
6-1	22	367	9175	2.63
6-2	21	368	9200	2.86
7-1	25	206	5150	3.22
7-2	13	63	1575	2.79
9-1	22	356	8900	3.04
9-2	28	451	11275	3.11
10-1	16	186	4650	3.34
10-2	18	1426	35650	1.80
11-1	19	852	21300	1.07
11-2	17	547	13675	1.09
15-1	27	428	10700	2.53
15-2	15	222	5550	2.36
16-1	30	245	6125	3.72
16-2	16	111	2775	3.05
$\bar{x}$	19.9	358.7	8968	2.71
A-1	30	8804	80,845	1.17
A-2	20	13,930	127,916	1.24
B-1	35	3200	29,385	2.29
B-2	53	1718	15,776	3.33
C-1	18	28,384	260,643	1.49
C-2	14	11,344	104,169	1:58
D-1	22	4614	42,369	2.25
D-2	18	7106	65,253	1.69
E-1	40	2503	22,984	3.80
E-2	47	3642	33,444	3.98
F-1	29	484	4444	3.28
F-2	24	979	8990	2.73
$\bar{x}$	29.2	7225.6	66,352	2.40

restricted to hard bottoms; and (3) species which utilize the "detrital trap" provided by the macroalgae to augment their feeding and thereby reach maximum densities on hard bottoms though they are not absolutely restricted to them.

Dominant species in the first category on rock substratum in the Clinton Harbor system include the blue mussel, Mytilis edulis and the barnacle, Balanus improvisus. Both species compete with each other and other attached biota for space, which is a limiting resource in this type of habitat. This, combined with various sources of predation, produces pronounced seasonality in populations of these species. During the June, 1982 sampling, extremely dense populations of barnacles were present at many stations, but this may not necessarily be typical for the area.

Dominant species of the second type noted above included the two gastropods Lacuna vincta and Mitrella lunata. These species are a common and persistent component of shallow hard bottom communities in New England. The third type of species described above was represented at Clinton by the amphipods Jassa falcata, Corophium acutum and C. bonelli. Although these species were also ubiquitous throughout the sandy areas of the harbor, the densities seen at the rock sites were far greater than those seen in the sand areas.

As was anticipated, species richness and faunal density were greater at the rock stations than at the sand stations. Species richness (Table 3) varied from 14 to 53 species/$0.1m^2$ and, although this cannot be compared directly to the data for the sand stations because of the unequal sample sizes, the increase of nearly 50% per sample was greater than can be attributed to sample size alone.

The increase in faunal density, which can be normalized to individuals/m^2 and compared directly between habitats, was even more striking (Table 3). The mean density at the rock stations ($66,352/m^2$) was over seven times greater than that recorded from the sand substratum. The greatest density recorded from the rock samples was also over seven times greater than the highest recorded sand density ($260,643/m^2$ vs. $35,650/m^2$).

Diversities at the rock stations were generally lower than those recorded from the sand (Table 3). This is due to the tendency in such habitats of a single species to temporarily outcompete others for available resources (e.g. space) and thereby establish extremely high densities. As noted above, for the present study this was particularly obvious for Balanus improvisus. The effect of this upon diversity is to produce lower values because the Shannon formula is overly sensitive to the proportional representation of the species.

3.3. Community Classification

The results of a normal, or Q-mode, classification analysis are presented in the form of a heirarchical dendrogram in Figure 3.

The most apparent dichotomy in the dendrogram is the clear and complete separation between the sand and rock stations. No rock station clustered with the sand group, and vice-versa; the two groups join only at very low levels of similarity. Although this result is hardly surprising in light of the previous discussion and even a casual examination of the data, it does graphically demonstrate the profound effect of substratum type on the structure of the benthic faunal community. Since, in some cases, these rock and sand communities co-exist less than 100m from each other, they share the same physical regime except for substratum.

Considering the groupings within each substratum cluster, the sand stations 5, 11, and 15 form a cluster which is apparently due to the presence of the polychaete Scolecolepides viridis as a dominant species with the amphipod Jassa falcata as a sub-dominant. High proportional densities of Scolecolepides were restricted to these three stations, which do not form a contiguous identifiable zone within the harbor (Figure 4).

A second group within the sand substratum cluster includes stations 6 and 7 and one of the replicates at station 2. This cluster includes stations which were dominated by Streblospio benedicti and Tellina agilis with Scolecolepides also present as a sub-dominant in most cases. This faunal group appears to be similar in composition to group III as identified from the September, 1981 samples and to groups IV and VI from the October samples, and, in its various forms, appears to be the most representative assemblage of the harbor. Stations 10 and 16 in June were
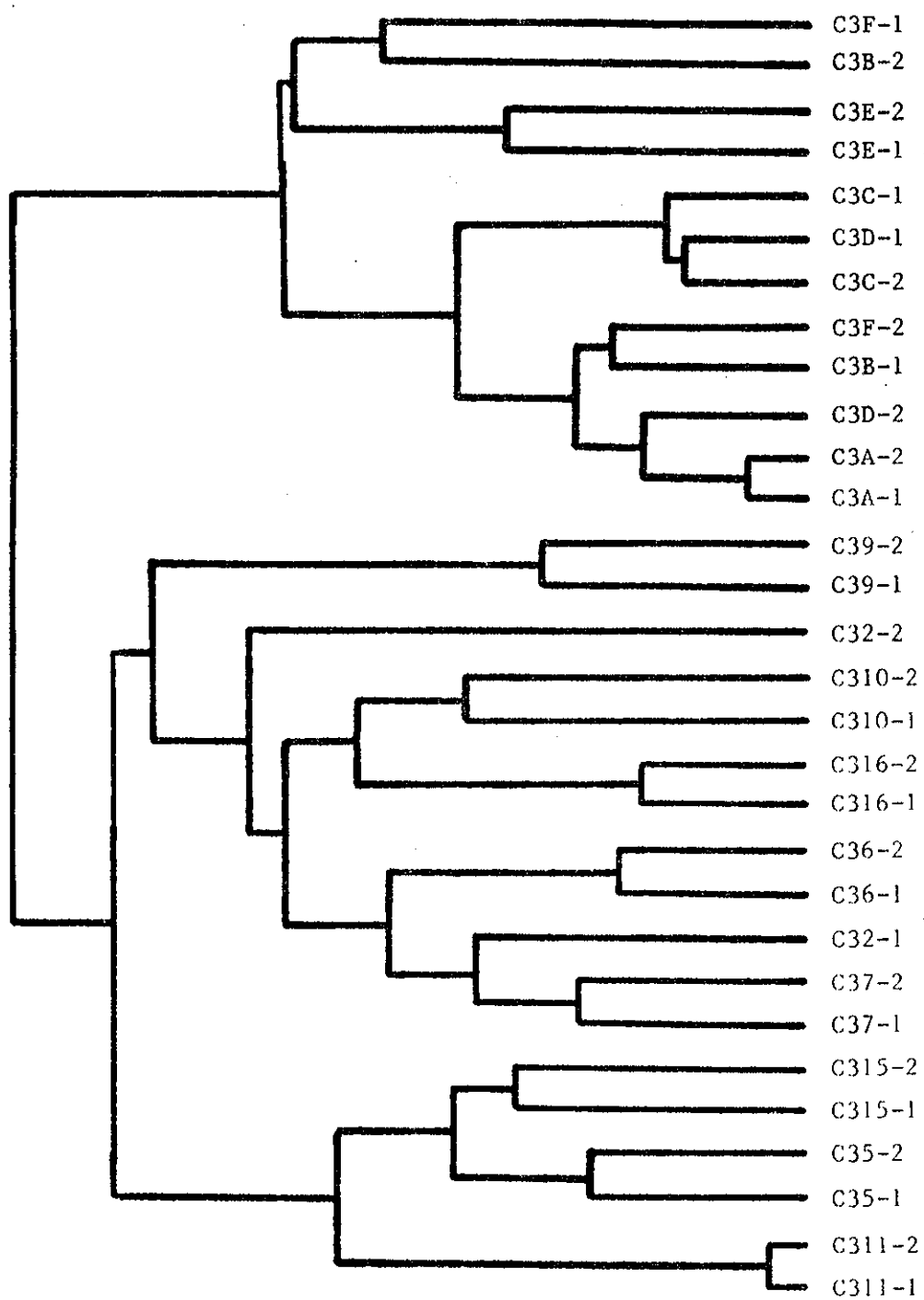
12

Figure 3: Heirarchichal dendrogram showing relationships among
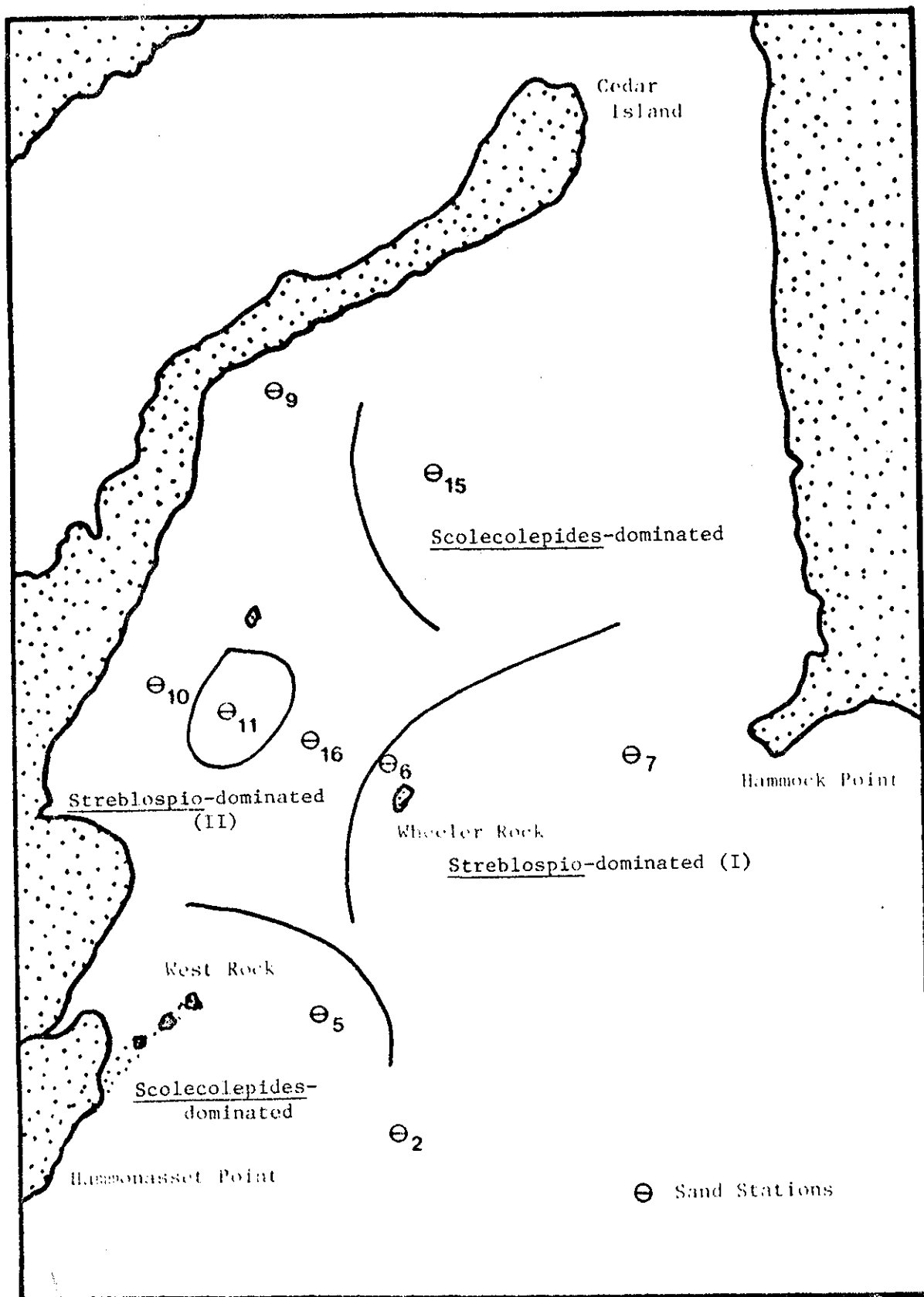stations sampled in June, 1982, at Clinton Harbor.

Figure 4: Community type distribution in June, 1982 at Clinton Harbor.

14

closely related to this cluster, differing primarily in the proportional representation of such species as Pygospio elegans and Gemma gemma. Considered together, this cluster physically occupies a large area of the central harbor (Figure 4).

Within the rock cluster, the primary dichotomy is between Station E and one replicate each from Stations B and F, and the remainder of the samples. This is directly attributable to the proportional representation of barnacles at these sites. Station E, at Wheeler Rock, was necessarily sampled below the barnacle zone. The other two samples, although barnacles were present, do not show the degree of dominance by this species which is characteristic of the other samples. This is presumably due to small-scale patchiness caused by microhabitat variation or predation.

All the remaining rock stations were strongly dominated by Balanus improvisus but were separated into two groups according to their sub-dominants. The group which included both replicates from Station A plus single replicates from Stations B, D, and F was characterized by dense populations of the gastropods Mitrella and Lacuna. The remaining small group was characterized by dense populations of detritovorous amphipods (Jassa and Corophium spp.).

With the exception of Station E (Wheeler Rock) the reason for the differences among the rock stations is not clear. Presumably, minor and essentially unnoticeable differences in microclimate and exposure are sufficient to produce more substantial changes in the resident fauna in such communities.

4.0. RESULTS (ALGAE)

4.1. Species Richness

A total of 40 algal species was recorded from the six Clinton Harbor subtidal rock-substratum stations (Table 4). Species richness was moderately high and generally uniform for all stations and replicates throughout the survey area (Table 5). No single station or replicate contained all 40 species. The number of species contained in the individual replicates showed moderate variation, ranging from a minimum of 10 to a maximum of 22; the mean number of species per replicate was 15.6. The total number of species recorded for each station showed somewhat less

Table 4. Algal species occurrence and biomass (g/m^2) from the replicate samples of the Clinton Harbor rock substratum stations.

Division Species	A 1	A 2	B 1	B 2	C 1	C 2	D 1	D 2	E 1	E 2	F 1	F 2
Green algae (Chlorophyta)												
Chaetomorpha linum	-	P	-	-	-	-	-	-	-	-	-	-
Cladophora albida	-	-	-	-	-	-	-	-	P	-	-	-
Cladophora glaucescens	-	-	-	-	-	-	-	-	-	P	-	-
Cladophora ssp.	-	P	-	-	-	-	-	-	-	-	P	-
Enteromorpha clathrata	-	-	-	P	-	-	-	-	-	-	-	P
Enteromorpha flexuosa	P	-	-	P	-	P	-	-	-	-	-	P
Enteromorpha intestinalis	-	P	-	-	-	-	-	-	-	-	-	-
Enteromorpha linza	-	P	-	-	P	P	P	P	-	P	-	P
Enteromorpha spp.	-	P	-	P	-	-	P	-	-	-	-	P
Monostroma grevillei	P	10.1	P	P	1.5	P	P	P	-	P	P	-
Spongomorpha aeruginosa	-	-	-	-	P	-	-	-	-	-	-	-
Spongomorpha arcta	-	-	P	-	-	P	P	-	P	P	-	-
Ulothrix flacca	-	-	-	-	-	-	-	-	-	-	-	P
Ulva lactuca	P	P	P	P	6.7	12.0	11.9	25.3	P	P	P	P
Brown algae (Phaeophyta)												
Desmarestia aculeata	-	-	-	-	-	-	-	-	-	P	-	-
Desmarestia viridis	-	-	P	P	P	P	-	-	P	P	-	-
Ectocarpus confervoides	-	P	-	-	1.3	P	1.4	P	P	5.1	-	-
Giffordia granulosa	-	-	-	-	-	-	-	-	-	P	-	-
Laminaria saccharina	P	P	-	-	9.1	1.1	8.8	48.3	46.3	37.6	-	P
Petalonia fascia	3.5	4.9	-	-	P	P	P	P	-	-	P	P
Pilayella littoralis	-	-	P	P	19.6	21.1	22.5	20.0	4.3	P	-	-
Punctaria latifolia	-	P	-	-	-	-	-	-	-	-	-	P
Scytosiphon lomentaria	3.5	30.4	-	-	3.8	P	P	P	-	P	P	-

16

Table 4. (continued)

Division Species	Station and Replicate A		B		C		D		E		F	
	1	2	1	2	1	2	1	2	1	2	1	2
Red algae (Rhodophyta)												
Ahnfeltia plicata	1.3	P	–	–	P	P	–	P	P	–	–	–
Antithamnion cruciatum	–	–	–	–	–	–	–	–	P	P	–	–
Callithamnion roseum	–	–	–	–	P	P	P	–	P	P	–	–
Ceramium rubrum	–	–	–	P	18.0	6.0	7.7	P	P	P	P	P
Chondrus crispus	229.1	270.1	916.3	706.1	393.8	316.6	307.4	298.5	–	P	353.0	583.3
Cystoclonium purpureum	P	–	P	P	–	P	P	P	2.3	1.7	1.5	P
Dumontia incrassata	–	–	–	P	–	–	–	–	–	–	10.0	86.1
Goniotrichum alsidii	–	–	–	–	–	–	–	–	–	–	–	P
Gracilaria foliifera	–	–	–	–	–	–	–	–	–	P	–	–
Palmaria palmata	–	P	–	–	–	–	7.6	–	–	–	–	–
Phyllophora truncata	P	–	–	–	–	–	–	1.9	466.6	520.8	–	–
Polysiphonia denudata	–	P	–	–	–	–	–	–	–	–	–	–
Polysiphonia harveyi	P	–	–	–	P	P	–	–	–	P	P	–
Polysiphonia nigrescens	P	–	P	P	–	–	P	–	P	P	–	P
Polysiphonia urceolata	–	P	P	P	106.6	58.5	51.5	3.1	P	P	P	–
Porphyra leucosticta	P	1.6	P	–	2.2	2.5	1.9	P	–	–	–	–
Rhodomela confervoides	–	–	–	–	–	–	–	–	–	–	–	P

Legend: – = not present; P = biomass less than $1g/m^2$

Table 5. Algal species richness and community structure from the samples of the Clinton Harbor rock substratum stations a) by replicate, and b) by station.

a) By replicate

Station and replicate	Chlorophyta (green algae)	Phaeophyta (brown algae)	Rhodophyta (red algae)	Species richness
A,1	3 (23%)	3 (23%)	7 (54%)	13
A,2	7 (39%)	5 (28%)	6 (33%)	18
B,1	3 (30%)	2 (20%)	5 (50%)	10
B,2	5 (39%)	2 (15%)	6 (46%)	13
C,1	4 (24%)	6 (35%)	7 (41%)	17
C,2	5 (26%)	6 (32%)	8 (42%)	19
D,1	5 (28%)	5 (28%)	8 (44%)	18
D,2	3 (20%)	5 (33%)	7 (47%)	15
E,1	3 (20%)	4 (27%)	8 (53%)	15
E,2	5 (23%)	7 (32%)	10 (45%)	22
F,1	3 (27%)	2 (18%)	6 (55%)	11
F,2	6 (37%)	3 (19%)	7 (44%)	16

b) By station

Station	Chlorophyta (green algae)	Phaeophyta (brown algae)	Rhodophyta (red algae)	Species richness
A	8 (35%)	5 (22%)	10 (43%)	23
B	6 (40%)	2 (13%)	7 (47%)	15
C	6 (30%)	6 (30%)	8 (40%)	20
D	5 (25%)	5 (25%)	10 (50%)	20
E	6 (25%)	7 (29%)	11 (46%)	24
F	8 (38%)	4 (19%)	9 (43%)	21

variation, ranging from a low of 15 at Station B to a high of 24 at Station E; the mean number of species recorded at each station was 20.5.

The number of species representing each of the major algal divisions was also similar for all six stations (Table 5). Red algal species (Rhodophyta) predominated throughout the survey area, comprising between 40 and 50% of the total species number at the individual stations. Green algal species (Chlorophyta) and brown algal species (Phaeophyta) were less well represented; green algae accounted for between 25 and 40% of the total species number at each station, while brown algal composition ranged between 13 and 30%.

4.2. Community Overlap

Community overlap analyses, which provide a measure of the degree of similarity in species composition between stations, were performed using Jaccard's Coefficient of Community (Grieg-Smith, 1964). The results (Table 6) showed overlap to be moderately high and relatively uniform for all station pairs, ranging from a low of 26.7% to a high of 66.7%; the average overlap value was 46.7%. These data indicate that algal species composition was generally uniform throughout the six-station survey zone.

4.3. Species Dominance and Community Structure

Assessments of algal species dominance and community structure for all stations were based upon biomass determinations. Replicate biomass values are included in Table 4 for each species displaying biomass of 1 g/m^2 or greater. Table 7 lists the mean station biomass value for all species with biomass greater than 1 g/m^2 in at least one replicate. The tables show that dense populations of the red algal benthic macroscopic carrageenoids Chondrus crispus and Phyllophora truncata dominated all six stations. Chondrus was the dominant taxa at all stations except E, with biomass ranging from 249.6 g/m^2 at Station A to 811.2 g/m^2 at Station B. Chondrus' dominance is further illustrated by viewing Chondrus biomass as a proportion of total algal biomass at each station (Table 7). Chondrus biomass is seen to comprise between 72% (Station C) and 99% (Station B) of total station biomass at the five locations. Station E (Wheeler Rock) was dominated by Phyllophora, which showed biomass of 493.7 g/m^2 and accounted for 91% of the total station biomass. The replacement of Chondrus by Phyllophora at Station E is primarily a function of depth; Station E

19

Table 6. Community overlap (Jaccard's Coefficient of Community) between the
Clinton Harbor rock substratum stations.

Station pair	number of shared species	community overlap
A/B	8	26.7%
A/C	14	48.3%
A/D	16	59.3%
A/E	13	38.2%
A/F	15	51.7%
B/C	11	45.8%
B/D	11	45.8%
B/E	10	34.5%
B/F	11	44.0%
C/D	16	66.7%
C/E	16	57.1%
C/F	12	41.4%
D/E	16	66.7%
D/F	12	41.4%
E/F	11	32.4%
Mean value	12.8	46.7%

Table 7. Algal biomass (g/m^2) and percent composition of the dominant species from the Clinton Harbor rock substratum stations.

Species	Station					
	A	B	C	D	E	F
Chondrus crispus	249.6 (90%)	811.2 (99%)	355.2 (72%)	302.9 (73%)	P	468.1 (90%)
Phyllophora truncata	P	–	–	1.0 (<1%)	493.7 (91%)	–
Laminaria saccharina	P	–	5.1 (1%)	28.5 (7%)	41.9 (8%)	P
Ulva lactuca	P	P	9.4 (2%)	18.6 (5%)	P	P
Pilayella littoralis	–	P	20.3 (4%)	21.3 (5%)	2.2 (<1%)	P
Scytosiphon lomentaria	16.9 (6%)	–	1.9 (<1%)	P	P	P
Polysiphonia urceolata	P	P	82.5 (17%)	27.3 (7%)	P	P
Ceramium rubrum	–	P	12.0 (2%)	3.9 (1%)	P	P
Dumontia incrassata	–	P	–	–	–	48.0 (9%)
Porphyra leucosticta	0.8 (<1%)	P	2.4 (1%)	1.0 (<1%)	–	–
Cystoclonium purpureum	P	P	P	P	2.0 (<1%)	0.8 (<1%)
Ectocarpus confervoides	P	–	0.7 (<1%)	0.7 (<1%)	2.6 (1%)	–
Monostroma grevillei	5.1 (2%)	P	0.8 (<1%)	P	P	P
Ahnfeltia plicata	0.7 (<1%)	–	P	P	P	–
Petalonia fascia	4.2 (2%)	–	P	P	–	P
Palmaria palmata	P	–	–	3.8 (1%)	–	–
All other species	1.2 (<1%)	2.9 (1%)	1.8 (<1%)	3.7 (1%)	1.4 (<1%)	0.8 (<1%)
Total algal biomass	278.5	814.1	492.1	412.7	543.8	517.7

Legend: – = not present; P = biomass less than 1g/m^2.

(-8' MLW) is particularly well suited for colonization by <u>Phyllophora</u>, which is known to achieve maximal growth and density in waters of moderate depth.

Benthic species other than <u>Chondrus</u> and <u>Phyllophora</u> were poorly represented at all six stations due to an overall inability to success- fully compete with the dominant carrageenoids. The benthic species <u>Laminaria saccharina</u>, <u>Ulva lactuca</u>, <u>Scytosiphon lomentaria</u>, <u>Monostroma grevillei</u>, and <u>Petalonia fascia</u> were recorded from the majority of stations (Tables 4,7). However, biomass for each species did not exceed 50 g/m^2 at any station, and was considerably less at most. The percent composition for each species was likewise reduced, with the biomass of each species not exceeding 10% of total algal biomass at any station.

Epiphytic algal populations were present in varying degrees of abundance at all six stations, with <u>Chondrus</u> and <u>Phyllophora</u> serving as the principal host species. The epiphytic populations were most well developed at stations C and D, least well developed at station A, B, and F, and of average development at station E (Table 7). The dominant epi- phytic species, which were recorded from the majority of stations, were <u>Pilayella littoralis</u>, <u>Ceramium rubrum</u>, <u>Cystoclonium purpureum</u>, <u>Ectocarpus confervoides</u>, and <u>Polysiphonia urceolata</u>. Although the epiphytic species contributed substantially to overall species richness at all stations throughout the survey area, they contributed only minimally towards station biomass; epiphytic species biomass exceeded 100 g/m^2 only at station C, and did not exceed 25% of total algal biomass at any stations.

4.4. <u>Algal Biomass</u>

As biomass data for the individual species has been addressed in the previous section, only total station biomass will be considered here. Total station biomass showed considerable variation, ranging from a low of 278.5 g/m^2 at station A to 814.1 g/m^2 at station B; the mean station biomass for the entire six station survey area was 509.8 (Table 7). All values are similar to those recorded for similar habitats throughout New England.

5.0. DISCUSSION AND CONCLUSIONS

Although it is not possible to address seasonality in the Clinton Harbor infauna on the basis of essentially two seasonal collections, we now know that the benthic communities in the proposed container disposal area do not appear to change radically between Spring and Fall. The results of this survey indicate that most of the species which have been described as important faunal components in previous collections are also present in the Spring but that, in some cases, their positions as dominants in the community are taken over by other related species.

The actual taxonomic composition of the infaunal communities on a seasonal basis is probably of less importance for the Clinton Harbor system than the community parameters of species richness, faunal density, and diversity. If we view the benthos as secondary producers whose role in the ecosystem is to convert energy into forms which become available to higher trophic levels, then it is apparent that, in general, the seasonal change from dominance by one species to dominance by another related species (for example, from Streblospio to Scolecolepides in the present case) is of less significance than large changes in the numbers of organisms present.

When viewed from this perspective, the amount of seasonality evident at Clinton is minimal. The present collections indicate moderate increases in species richness and faunal density in these infaunal communities but these changes are not of sufficient magnitude to alter the functional relationships between the benthos and other components of the ecosystem.

The resident hard bottom biotic community at Clinton Harbor is typical of such habitats throughout New England. The red algal species Chondrus crispus and Phyllophora truncata (collectively harvested in some areas as Irish moss) were the dominant algae at all sites and both the algal and faunal components of this habitat had elevated species diversity and standing stocks.

The ecological value of this type of community is multifaceted. The high algal density produces a zone of benthic primary production which is essentially absent from soft bottom communities. The physical nature of the algal cover, particularly the dense mat produced by Chondrus and Phyllophora creates an ideal breeding and foraging habitat for many faunal

species producing much greater population densities than would otherwise be possible. The creation of additional habitat of this kind at Clinton would be one of the unquestionalble benefits of the proposed container disposal construction.

In comparison to a similar Long Island Sound hard bottom community for which similar data are available, Black Ledge - New London Harbor (McGrath et al., 1982a), the algal populations at Clinton were found to be of considerably greater ecological value. Algal populations at Black Ledge were adversely impacted by a dense population of mussels (Mytilis edulis) which prevented the establishment of a healthy Chondrus/Phyllophora community. Although this resulted in greater algal species diversity, the increase was among the small epiphytic species which do not contribute significantly fo the habitat value of the community.

The hard bottom faunal community at Clinton was generally more diverse than that at Black Ledge, again due to the overwhelming dominance of mussels at the latter site. As a result, although population densities were higher at Clinton, the amount of living biological material was greater at Black Ledge. In both cases, however, the rock communities supported far greater standing stocks than the surrounding soft bottoms, and it is expected that, for equivalent area, the surface of an artificial rock breakwater at Clinton would also be far more productive and ecologically valuable than the soft-bottom it would replace.

24

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APPENDIX 1

Faunal Raw Data, June, 1982

	2-1	2-2	5-1	5-2	6-1	6-2	7-1	7-2	9-1	9-2	10-1	10-2	11-1	11-2	15-1
ANNELIDA															
Scolecolepides viridis			109	48	92	128	1		1	25	3	17	714	462	132
Tharyx acutus		2	1	6	3	10	10	4	29	12	15	40	13	13	2
Oligochaeta									28	26	22	29	1	1	14
Asabellides oculata			2	2	7	11	21	2	1				4		
Harmothoe imbricata	2	2										10			
Streblospio benedicti	8	3		2	143	73	46	21		15	19	121	2		
Glycera americana			2	1	3		1				2	2	5	1	3
Mediomastus ambiseta	4	7			8	8	36	5			8	2			
Syllinae/Eusyllinae			2	2						39	34	44		2	
Prionospio steenstrupi	6	10			4	4	2	1	32						
Polygordius spp.		1	70	71	2	2	1								17
Exogone sp.			1							4			1		
Autolytus sp.			1				1						1		2
Polydora aggregata															
Sabellaria vulgaris															
Nereis pelagica															
Spiophanes bombyx		3			1	5							1		
Autolytus cornutus	1														
Paraonis fulgens			1						136	194	6		2		
Fabricia sabella															
Marphysa sanguinea															
Odontosyllis sp.							1			55					
Aricidea catharinae						5							71	30	1
Nephtys picta	4				14	47				3					
Phyllodocidae								1							1
Eteone heteropoda			1						20	13	6	65			
Polycirrus eximius															
Nephtys incisa		5					6	4							
Nephtydae			3	2					1				1		
Potamilla reniformis															
Anaitides groenlandica															
Orbiniidae				1								2			1
Pista palmata															
Autolytus fasciatus															
Maldanidae							9								
Sabella microphthalma															

	2-1	2-2	5-1	5-2	6-1	6-2	7-1	7-2	9-1	9-2	10-1	10-2	11-1	11-2	15-1
Archiannelida										3					187
Capitella capitata									1						
Polydora ligni				1											
Eumida sanguinea															
Parapionosyllis longicirrata															
Eteone lactea															1
Nicolea venustula															
Nereis sp.										1		10			1
Clymenella torquata								1		3					
Pygospio elegans			1									1011			
Pholoe minuta					1										
Polydora commensalis															
Lepidonotus squamatus															
Ampharetidae	4									3					
Nereidae															
Aricidea cerruti						2							7		
Polychaeta unid.															
Cirratulidae															
Hydroides dianthus															
Drilonereis longa						1									
Spionidae									1						
Dodecaceria corali															
Capitellidae									1						
Peloscolex benedeni											1				
Sphaerodoropsis minuta			1												
Potamilla sp.															
Sigalionidae							1								
Hesionidae										1					
Scoloplos acutus	2														
Dorvilleidae															1
Cirratulus grandis	3														
Anaitides mucosa															
Polydora caulleryi															
Nereis arenaceodonta															
Spio filicornis						2									

	2-1	2-2	5-1	5-2	6-1	6-2	7-1	7-2	9-1	9-2	10-1	10-2	11-1	11-2	15-1
MOLLUSCA															
Tellina agilis	19	8	30	13	60	55	51	18	10	9	19	6	6	7	13
Mytilis edulis		2					1								
Gemma gemma				1	1		1		19	23	39	33	3	11	12
Lacuna vincta															
Mitrella lunata									1			2			
Nassarius trivittatus	2							2					2	1	
Crepidula fornicata															
Littorina littorea															
Petricola pholadiformis															
Urosalpinx cinerea															
Anachis translirata															
Crepidula plana		1													
Mulinia lateralis							1								1
Onchidoris aspera															
Bittium alternatum									1						
Hiatella arctica															
Nucula annulata		3					2								
Anomia simplex															
Nucula delphinodonta	1														
Anomia aculeata															
Turbonilla elegantula					1										
Lunatia sp.															
Spisula solidissima		1													
Margarites umbilicalis															
Anadara transversa															
Gastropoda															
Ilyanassa obsoleta												2			
Odostomia gibbosa															
Turbonilla nivea							1								
Corambella sp.															

A-4

	2-1	2-2	5-1	5-2	6-1	6-2	7-1	7-2	9-1	9-2	10-1	10-2	11-1	11-2	15-1
CRUSTACEA															
Jassa falcata	1	14	74	23	12	4	3	2	25	33	8	26	16	8	11
Corophium bonelli	2	1	5	5	1	12	1		2		2	4		2	2
Corophium acutum	1	1	6	5	1		1		5	3			1	2	2
Marinogammarus stoerensis		3	4	1	6	5	4		1					1	1
Calliopius laevisculus		3		1		1			1	1		2			
Balanus improvisus															1
Caprella penantis															
Neopanope sayi															
Aeginina longicornis										1					
Erichsonella filiformis															
Erichthonius brasiliensis															
Idotea balthica															
Ostracoda				1					1	15				1	10
Pagurus longicarpus													1	3	
Leucon americanus		1			1	1									
Idotea phosphorea								1							
Unciola serrata															
Edotea triloba						2									
Leptochelia savignyi										2					1
Corophium simile															
Paraphoxus spinosus															
Trichophoxus epistomus															5
Oxyurostylis smithi														1	
Cancer irroratus															
Elasmopus levis															
Phoxichilidium femoratum															
Gammarus oceanicus															
Cyathura polita										1					
Phoxocephalus holbolli															
Monoculodes edwardsi															1
Caprellidae															
Decapoda															
Jaera marina															
Pseudoleptocuma minor					1										
Libinia dubia															
Tanystylum orbiculare															

	2-1	2-2	5-1	5-2	6-1	6-2	7-1	7-2	9-1	9-2	10-1	10-2	11-1	11-2	15-1
Unciola irrorata					4	1	3	1							
Pycnogonida										1					
Stenothoe minuta															
Photis sp.															
Ampelisca abdita										1					
Cumacea										1					
Proboloides holmesi														1	

ECHINODERMATA

	2-1	2-2	5-1	5-2	6-1	6-2	7-1	7-2	9-1	9-2	10-1	10-2	11-1	11-2	15-1
Amphipholis squamata										1					

MISCELLANEOUS

	2-1	2-2	5-1	5-2	6-1	6-2	7-1	7-2	9-1	9-2	10-1	10-2	11-1	11-2	15-1
Nemertea					1			1							
Metridium senile															5
Turbellaria															
Euplana gracilis										1					
Sipunculoidea															

	15-2	16-1	16-2	A-1	A-2	B-1	B-2	C-1	C-2	D-1	D-2	E-1	E-2	F-1	F-2
ANNELIDA															
Scolecolepides viridis	36	1	1							2		16			
Tharyx acutus		39	34												
Oligochaeta	2	12	9	1			4	12							
Asabellides oculata		9	4	1			1					8	28		
Harmothoe imbricata				87	62	68	89		8	20	36	600	882	25	20
Streblospio benedicti		52	24												
Glycera americana	1						1								
Mediomastus ambiseta		13	3												
Syllinae/Eusyllinae		2	1	2											
Prionospio steenstrupi		26	12												
Polygordius spp.	6	1													
Exogone sp.		1				2	6					12	36		
Autolytus sp.		1		6								3			
Polydora aggregata				160	124		26	8	4	4				12	
Sabellaria vulgaris		1		6		48	13						20	3	12
Nereis pelagica				18	14		6	8	4	18	8	4			
Spiophanes bombyx	2	1													
Autolytus cornutus						3	1					96	176	1	
Paraonis fulgens						1									
Fabricia sabella				5	16		2	148		10					
Marphysa sanguinea				1		6	8					8		3	
Odontosyllis sp.							8					164	148		
Aricidea catharinae												4			
Nephtys picta	5														
Phyllodocidae							1						8		1
Eteone heteropoda															
Polycirrus eximius				2	2		19						8		
Nephtys incisa			1												
Nephtydae		1													
Potamilla reniformis						2	1					12	16		
Anaitides groenlandica							1					12	4		
Orbiniidae															
Pista palmata				1		3							240		
Autolytus fasciatus							6					16	20		
Maldanidae							1						28		
Sabella microphthalma							3					24	60		

	15-2	16-1	16-2	A-1	A-2	B-1	B-2	C-1	C-2	D-1	D-2	E-1	E-2	F-1	F-2
Archiannelida	119														
Capitella capitata		1		1				—							
Polydora ligni						15							8		
Eumida sanguinea							1						8	1	
Parapionosyllis longicirrata							3					16	32		
Eteone lactea		1													
Nicolea venustula							14					32			
Nereis sp.															
Clymenella torquata															
Pygospio elegans															
Pholoe minuta												4			
Polydora commensalis													12		3
Lepidonotus squamatus							16					20			
Ampharetidae															
Nereidae													4		
Aricidea cerruti															
Polychaeta unid.							1					12			
Cirratulidae					2										
Hydroides dianthus						2									
Drilonereis longa															
Spionidae															
Dodecaceria corali							1								
Capitellidae					4										
Peloscolex benedeni															
Sphaerodoropsis minuta															
Potamilla sp.															
Sigalionidae															
Hesionidae															
Scoloplos acutus															
Dorvilleidae															
Cirratulus grandis															
Anaitides mucosa														1	
Polydora caulleryi															
Nereis arenaceodonta															2
Spio filicornis															

	15-2	16-1	16-2	A-1	A-2	B-1	B-2	C-1	C-2	D-1	D-2	E-1	E-2	F-1	F-2
MOLLUSCA															
Tellina agilis	19	7	3			3	2			2		80	120	3	
Mytilis edulis				203	338	45	10	584	232	290	180	4	88	2	6
Gemma gemma	2	1													
Lacuna vincta				270	152	355	390	60	76	110	144	240	120	64	106
Mitrella lunata						64	98	4		40	8	488	232	126	139
Nassarius trivittatus				1										3	15
Crepidula fornicata				6		2	5						4	3	23
Littorina littorea				5	20	29	15							27	50
Petricola pholadiformis					2	2	1			4	4				
Urosalpinx cinerea						3	3				4			14	17
Anachis translirata						4	1					56	56	1	
Crepidula plana				4								16		1	
Mulinia lateralis	3														
Onchidoris aspera						5	1								3
Bittium alternatum							1						4		
Hiatella arctica					4		2	4							
Nucula annulata															
Anomia simplex					1									1	
Nucula delphinodonta													8		
Anomia aculeata							5								
Turbonilla elegantula															
Lunatia sp.								16							
Spisula solidissima															
Margarites umbilicalis								4							
Anadara transversa												4			
Gastropoda												4			
Ilyanassa obsoleta															
Odostomia gibbosa													20		
Turbonilla nivea															
Corambella sp.													4		

	15-2	16-1	16-2	A-1	A-2	B-1	B-2	C-1	C-2	D-1	D-2	E-1	E-2	F-1	F-2
CRUSTACEA															
Jassa falcata	13	34	11	405	1284	650	420	12456	6096	1844	1232	180	76	13	72
Corophium bonelli	3	6		113	316	27	32	456	128	68	96	4	12	3	1
Corophium acutum	1	9	1	191	348	78	301	608	608	320	600	84	744	35	12
Marinogammarus stoerensis		1	2	2	24			32	16	28	8	20	4		4
Calliopius laevisculus			2	6	72	7	4	344	96	136	64		4	9	6
Balanus improvisus				7302	11136	1718	161	13836	4056	1668	4658			118	465
Caprella penantis							10	104	12	34	52	12	32		
Neopanope sayi						14	2		4		4		49	3	2
Aeginina longicornis		1					1			8		40	32	1	
Erichsonella filiformis						4	3				4	56	84	1	
Erichthonius brasiliensis						3	2					76	56	1	7
Idotea balthica						1	2	36	4		2				5
Ostracoda		5													
Pagurus longicarpus						1								8	7
Leucon americanus		4	2												1
Idotea phosphorea				1											
Unciola serrata				1		8	8								
Edotea triloba		1											4		
Leptochelia savignyi												4	4		
Corophium simile				1									4	1	
Paraphoxus spinosus															
Trichophoxus epistomus	9														
Oxyurostylis smithi			1												
Cancer irroratus							2				2				
Elasmopus levis							6	1					24		
Phoxichilidium femoratum								2							
Gammarus oceanicus								2							
Cyathura polita															
Phoxocephalus holbolli											2				
Monoculodes edwardsi															
Caprellidae	1											8			
Decapoda															
Jaera marina					2										
Pseudoleptocuma minor													8		
Libinia dubia													8		
Tanystylum orbiculare															

	15-2	16-1	16-2	A-1	A-2	B-1	B-2	C-1	C-2	D-1	D-2	E-1	E-2	F-1	F-2
Unciola irrorata															
Pycnogonida															
Stenothoe minuta													28		
Photis sp.				1											
Ampelisca abdita															
Cumacea															
Proboloides holmesi															
ECHINODERMATA															
Amphipholis squamata															
MISCELLANEOUS															
Nemertea				1	8		9					12	28		
Metridium senile							1			2	2	48	60		
Turbellaria		6							8						
Euplana gracilis												4			
Sipunculoidea										2					

A Report

to the

New England Division
Corps of Engineers
Department of the Army
Waltham, MA

CLINTON HARBOR, CT.
WAVE ENERGY ANALYSIS
AND
SEDIMENT TRANSPORT STUDY

by

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and

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for

The Center for the Environment and Man, Inc.

February 1983

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Background

The U.S. Army Corps of Engineers, New England Division
(CE/NED) is considering establishing a dredged material contain-
ment facility (DMCF) within the outer harbor of Clinton,
Connecticut. The proposal has arisen out of a CE/NED program
which has examined the preliminary feasibility for containment of
dredged materials at various locations throughout Long Island
Sound. Design of the Clinton Harbor DMCF is such that when com-
pleted it will allow establishment of new tidal marsh using
dredged material from the Clinton Harbor navigation project.

During March 1982, evaluations of the feasibility and
probable environmental impacts associated with the DMCF were
completed (Taxon, 1982). The Executive Summary of that report is
included as Appendix A of this report.

The environmental report hypothesized that a major potential
impact of the proposed DMCF could be modification of the local
wave climate due to construction induced changes in wave refrac-
tion/diffraction patterns. Such modifications could be sufficient
to produce significant variations in local sediment transport
which could complicate maintenance of the Clinton Harbor
navigation channel and the stability of adjacent shallow
submerged sand deposits. The report addressed in detail tidal
current patterns and projected changes due to the DMCF.

This report presents results of study directed to examining
the probable sediment transport effects of DMCF placement in
Clinton Harbor. Detailed information is presented on the existing

1

Wave Ray Tracing Area
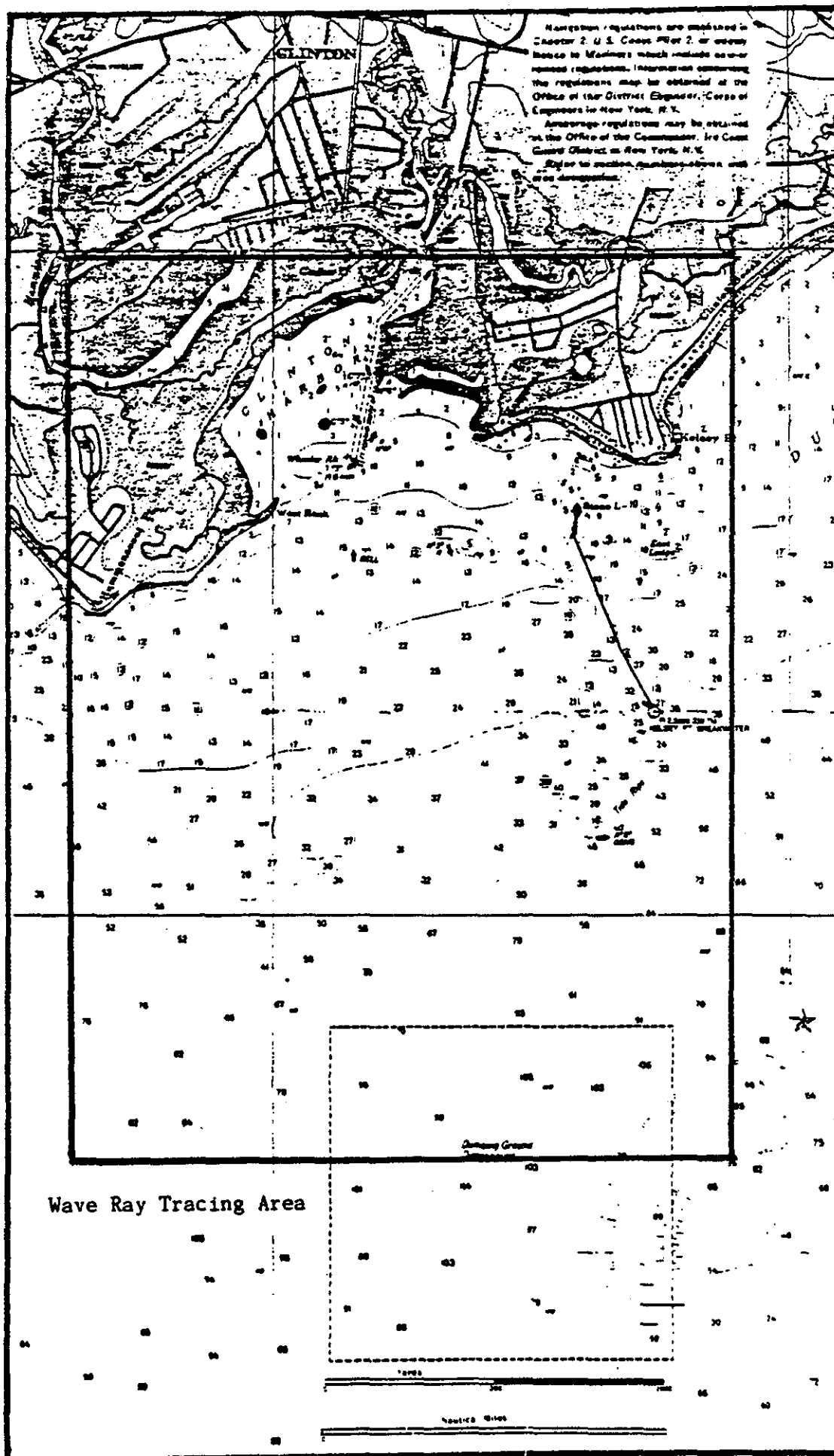
Figure 1-1. Clinton Harbor Study Area

2

sediment transport regime, wave energy conditions, and possible changes in such conditions ascribable to the DMCF. In combination with the earlier environmental report, the reports provide a comprehensive assessment of the environmental feasibility of the DMCF.

1.2 Objective

The objective of this study is to examine the potential impact of the proposed DMCF at Clinton Harbor on sediment erosion and deposition patterns. Results of the study will ensure DMCF feasibility, lend guidance to DMCF design, and provide information appropriate for inclusion in the Environmental Impact Statement for the project.

1.3 Scope

The scope of work to accomplish project objectives involves the following activities and analyses:

o Review of the historical character of the sediment transport system affecting the coastal area within and adjacent to Clinton Harbor. Qualitative analysis of the extent to which waves and tidal currents presently affect local sediment transport. Field reconnaissance consisting of visual survey of existing sediment characteristics and features of the shoreline and shallow subtidal zones.

o Application of state-of-the-art wave refraction analysis methods -- using as input Long Island Sound wave characteristics -- to determine possible changes in the existing wave energy regime due to DMCF placement. Assessment of the impact of the DMCF on the local sediment transport system -- including combined wave and tidal current energy effects. Suggest alternative DMCF

dike alignment angles to minimize possible sediment transport impacts if difficulties are predicted.

1.4 Outline of Report

Section 2 presents an overview of the DMCF project including details on the alignment and design of the containment dikes. Section 3 includes information on Site Characteristics and reviews local environmental conditions, historical and existing sediment transport characteristics, and wave and tidal current characteristics. Evaluation of DMCF sediment transport impacts is presented in Section 4. Conclusions and Recommendations are presented in Section 5. Appendices present background information on previous studies of the Clinton Harbor DMCF and selected computer output results.

2.0 PROJECT DESCRIPTION

Consideration of a dredged material containment facility (DMCF) in Clinton Harbor has been in part motivated by a desire to demonstrate the feasibility of the method for stabilizing dredged materials as well as to enhance environmental conditions. A DMCF is a structure designed to prevent migration of dredged material away from the disposal site which could refill the channel or cause adverse environmental effects.

The proposed disposal location, as shown on Figure 2-1, is located to the west of the Federal navigation channel and adjacent to existing beach and tidal marsh lands near Hammonasset State Park. The DMCF would be developed by construction of a containment dike and subsequent placement of dredged materials behind the dike. In its final form, the DMCF would provide for channels behind the dikes for tidal movement, with vegetative areas in-between. The area would be similar to the neighboring marsh and would provide a diversity of habitat types. The recommended sequential marsh development scheme for dredged material disposal and habitat development is detailed in the Site Evaluation report (Taxon, 1982). That plan suggested breeching the DMCF dike near Cedar Island to permit tidal circulation to the DMCF interior.

Because the objective of the Clinton Harbor DMCF is expansion and protection of tidal marsh, only a low dike need be constructed. Figure 2-2 shows a typical cross-section of the dike structure for the south-facing portion of the DMCF. The section shown is for the higher energy portion of the structure and provision is made for protection against erosive wave action by
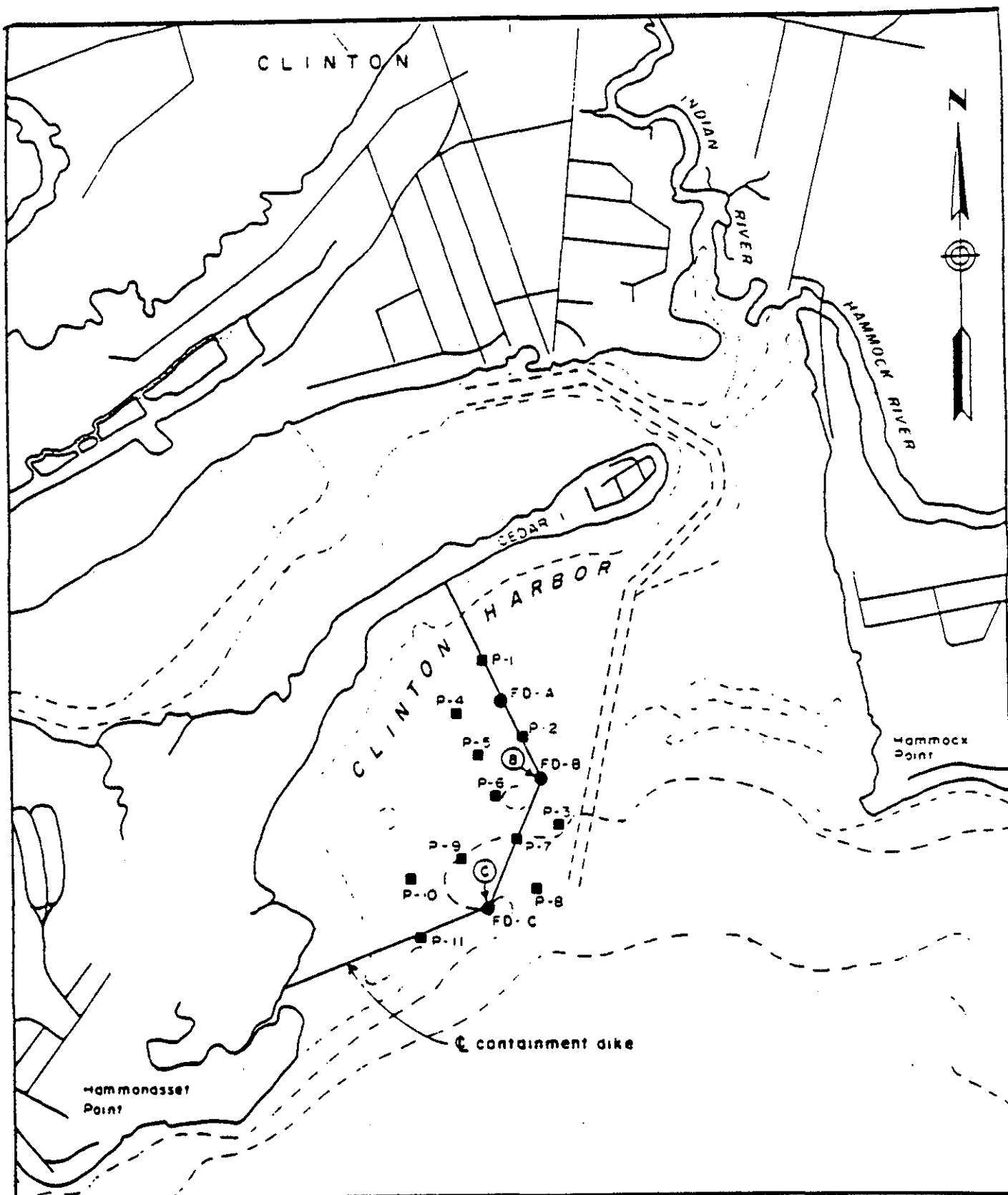
Figure 2-1. Location of Containment Facility

CONTAINMENT SIDE   OCEAN SIDE
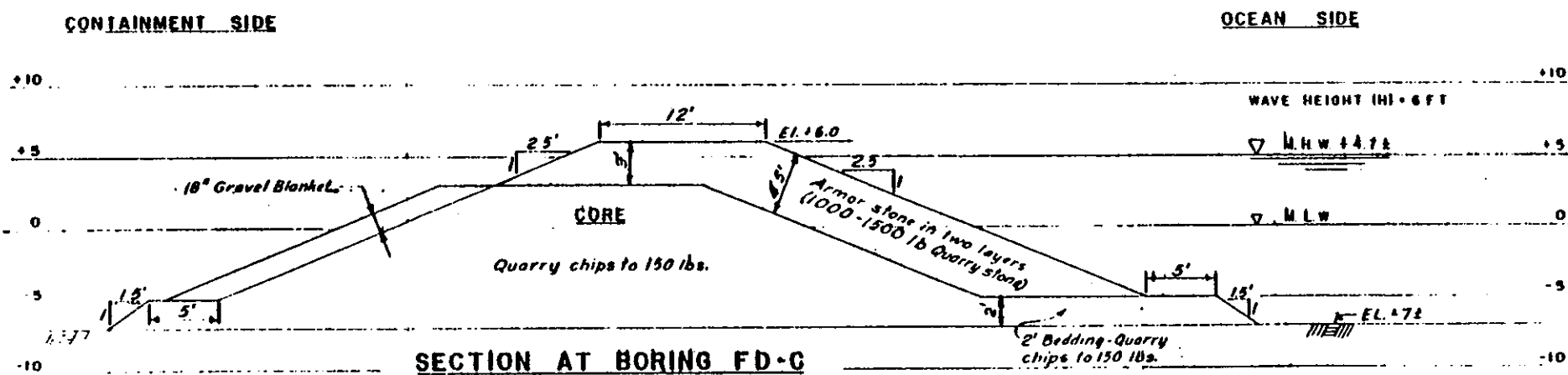
Figure 2-2. Cross Section of Containment Dike

placement of coarse armor stone on the dike face. Smaller armor stone is proposed for the east-facing dike sections which are shielded from wave action.

3.0 SITE CHARACTERISTICS

3.1 Geology and Geomorphology

Clinton Harbor is a shallow embayment located approximately 9nm (nautical miles) to the west of the Connecticut River along the north shore of Long Island Sound. This basin receives the discharge from the Hammonasset and Indian Rivers which exit south bisecting an area bordered by remnant end moraines (Flint,1971). These latter structures represented by Hammock Point and Hammonasset Point form respectively the eastern and western boundaries of the entrance to Clinton Harbor (Figure 1-1). From Hammonasset Point, the outline of the northwestern limit of the Harbor is controlled by a northeast tending sand spit supporting some limited residential development near its distal end. The eastern shoreline formed primarily by mechanical placement of fill extends northerly for three-quarters of a mile from Hammock Point bridging several morainal remants and supporting a generally high density of residential development. The backshore areas adjacent to both the eastern and western limits of the Harbor consist primarily of tidal marshes which form a large resistant structure extending shorewards to establish the downstream boundaries of the entering tributary river.

Surficial sediments within Clinton Harbor consist primarily of fine to medium sands with occasional pockets of finer grained silts, particularly in the vicinity of the dredged navigational channel, and coarser grained gravels, cobbles, and boulders adjacent to the headlands. The majority of this material is glacial in origin and has been supplied by the combined effects of meltwater runoff and the erosion of assorted till and drift material

9

characterizing local moraines. As noted above these latter structures appear at several locations adjacent to Clinton Harbor and are also observed at several further offshore sites. The erosion and distribution of materials associated with these moraines is considered to represent the primary source of offshore sediment to Clinton Harbor.

3.2 Regional Bathymetry

Sediment distributions within Clinton Harbor favor generalized shoaling resulting in average depths of approximately 2 to 3 ft at mean low water. Depths display a slight east-west assymmetry with minima occurring to the east of the dredged navigational channel where a broad tidal flat is in large part exposed during low water periods (Figure 1-1). To the west of the channel depths seldom fall below 1 to 2 ft. Throughout the area bottom slopes are extremely gradual and average approximately 1:400 from the shoreline out to the 6 ft contour. Beyond this point slopes increase slowly but progressively with values increasing from 1:300 near the 12 ft isobath to 1:150 near the 72 ft contour approximately 1.7nm south of the Harbor entrance. Both the inshore and offshore slopes are interrupted occasionally by shoals consisting of boulders and assorted glacial till. Most of these structures display limited spatial scale and represent minimal influence on local geomorphology. Inshore, only the shoals in the vicinity of Hammonasset Point and Hammock Point appear of sufficient scale to modify local circulation or the incoming wave field. Such effects should be particularly pronounced in the vicinity of Hammock Point due to the presence

10

of the Kelsey Point Breakwater; a free-standing, emergent struc-
ture extending to the southeast of Stone Island for a distance of
approximately 3600 ft (Figure 1-1). Offshore only shoals asso-
ciated with Falkner Island, 5.5nm southwest of Hammonasset Point,
Six Mile Reef, 4nm southeast of the Point and Long Sand Shoal 5nm
east-southeast of the Point appear sufficient to modify local
hydrography affecting transport within and adjacent to Clinton
Harbor.

3.3 Meterological Conditions

3.3.1 Winds

The wind field active in the vicinity of Clinton can be
expected to display a regular seasonal pattern with southwesterly
winds, dominating during the summer months and northwesterly
winds during the winter. High energy, aperiodic storm events
typically dominated by northeasterly winds, can occur at any time
during the year (Brumbach,1965). Wind velocities display a simi-
lar seasonal pattern with maxima occurring during the fall and
winter months and minima during the late summer. A representa-
tive seasonal cycle developed using data obtained from the
meteorological tower maintained by Northeast Utilities at Mill-
stone Point near Niantic, Connecticut is shown in Figure 3-1. The
indicated stress is proportional to the square of the wind speed.

3.3.2 Air Temperature

The annual average air temperature for the coastal region in
the vicinity of Clinton is approximately 60°F. Annual maxima
typically occur during July and August and seldom exceed 90°F.
Minima occur during late January and February with values ranging
down to 0°F. These late winter conditions generally result in

11
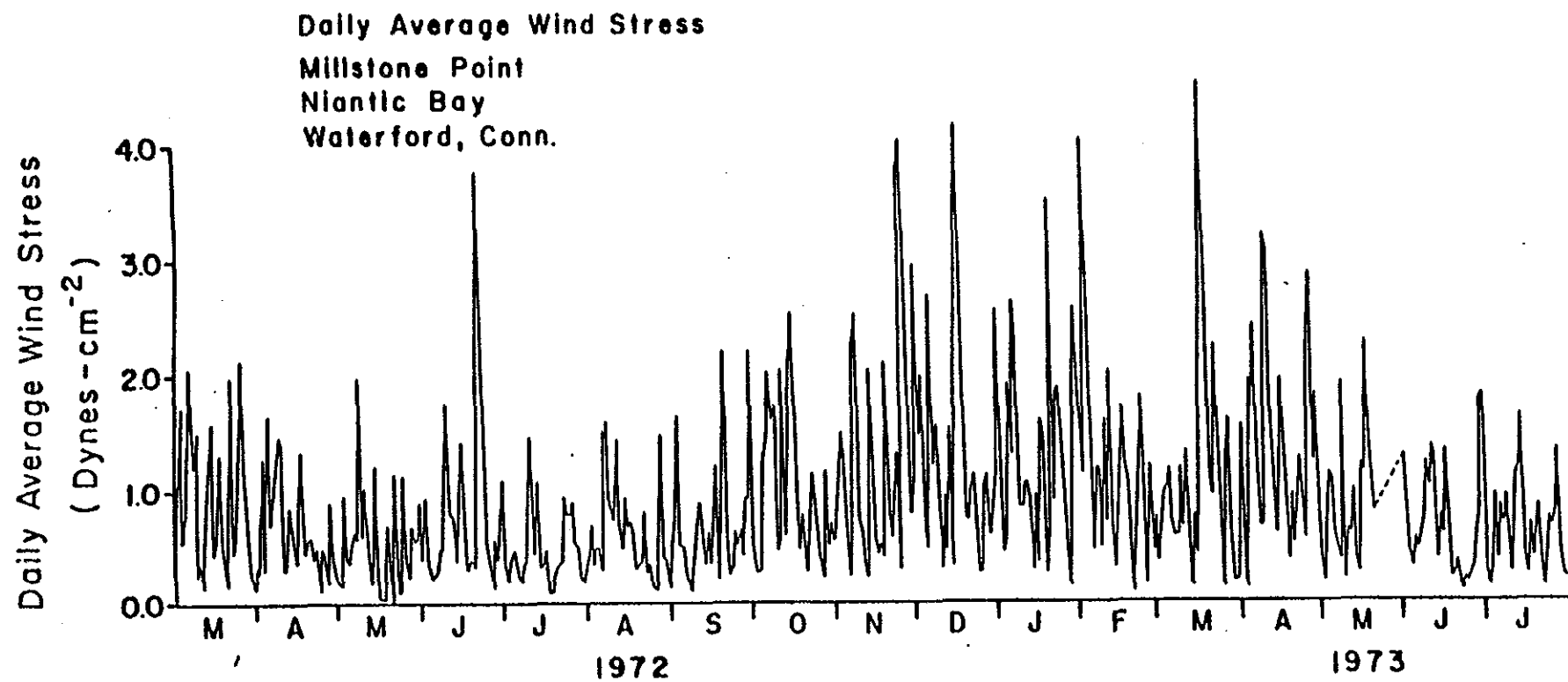
Figure 3-1. Daily Average Wind Stress

persistent ice cover within the inner sections of Clinton Harbor to the north and west of Cedar Island (Figure 1-1). Significant ice cover within the more open waters of the Harbor is limited to periods of extreme lasting cold which infrequently occur. Reviews of temperature records for the period 1931 through the present indicates probable significant ice coverage in the Harbor occurring on a frequency of approximately once every five to ten years.

3.3.3 Precipitation

Precipitation in the Clinton area displays a weak seasonality with maxima occurring during late fall, winter, and early spring. Minima typically occur during the mid-summer months. Monthly averages for each of the twelve months equal approximately 4 in producing an annual average of nearly 48 in (Brumbach,1965). During the late winter months approximately 25% of the average precipitation occurs in the form of snow.

3.4 Hydrographic Conditions

3.4.1 Tides and Tidal Currents

Tides in the vicinity of Clinton Harbor are dominantly semi-diurnal and display a mean range of approximately 4.5 ft and a spring range of 5.2 ft. Although relatively few direct observations are available, short-term surveys conducted as part of this study (Taxon, 1982) indicate tidal currents in the Harbor having maximum speeds of approximately 1 to 2 ft/sec. These maxima were observed in the navigational channel near the entrance to the inner Harbor adjacent to Cedar Island. Further offshore, along a line between Hammonasset and Hammock Points speeds were generally

lower and seldom exceeded 1 ft/sec. Associated flow directions were bathymetrically controlled and displayed a high degree of spatial variability. Proceeding inshore the flood tide displays a progressive variation in average flow direction varying from northwest going near the outer reaches of the Harbor through northgoing in mid-Harbor to northeasterly near the northern Harbor limits adjacent to Cedar Island. The ebb tide displays a similar pattern with a simple reversal in sense. Lagrangian drogue studies conducted to complement the current meter observations indicate that these average flow patterns can be significantly perturbed by varying wind stress conditions (Taxon,1982). These results appear consistent with the shallow depth conditions characterizing Clinton Harbor.

Average tidal conditions can be significantly modified during aperiodic storm events. Reviews of tidal flood data (U.S.A.C.E.,1973) indicate that storm events with 100 year recurrence intervals, such as the 1938 hurricane, can be expected to produce an increase in high water elevations in the Clinton area of approximately 7 ft. In combination with spring high water conditions, such a surge would result in sea level stands of approximately 12 ft above mean low water. Given the relatively low elevations of the lands surrounding Clinton Harbor such water levels would produce significant local flooding and favor initiation of major coastal erosion.

3.4.2 Sea Level

Local studies of sea level indicate a consistent, long term rise in Long Island Sound (Hicks,1968:1972). Although of secon-

14

dary importance as compared to other factors, variations in mean sea level are an important consideration when assessing long term trends in coastal evolution. Within Long Island Sound monthly sea level observations obtained at New London, Connecticut for the period 1939 to 1970 indicate annual increases in sea level of 0.00889 ft/yr and 0.01083 ft/yr respectively. Both sets of data display significant short term variability and during the period 1960-1965 favored a slight decrease in relative sea level stand. After 1965 this trend reversed and by 1970 sea level was approximately 0.032 ft above the level observed in 1960 at New London and 0.13 ft above the 1960 observation at Willets Point. The cause of these short period fluctuations is poorly understood.

3.4.3 Waves

The surface wave field in the area within and adjacent to Clinton Harbor is primarily the result of local wind generation. Swells propagating inshore from the adjacent continental shelf represent a relatively minor component of the total wave field and are effectively dissipated within the more easterly regions of the Long Island Sound. The narrow width of the Sound and its east-west orientation result in a fetch limited system favoring maximum wave generation by wind systems rich in easterly or westerly components. Observations provided by a bottom-mounted pressure transducer located south of Six Mile Reef in approximately 30 ft of water indicate that generation resulting from such systems will yield maximum energy wave spectra. Significant wave periods within these spectra will range from 3 to 12 seconds and maximum heights will equal approximately 6 feet (Bohlen, unpublished data, Figure 3-2). During inshore propagation these

Figure 3-2

SPECTRAL ANALYSIS
SIX MILE REEF WAVE GUAGE
15:00 AUGUST 27, 1982

FREQUENCY IN CYCLES PER SECOND
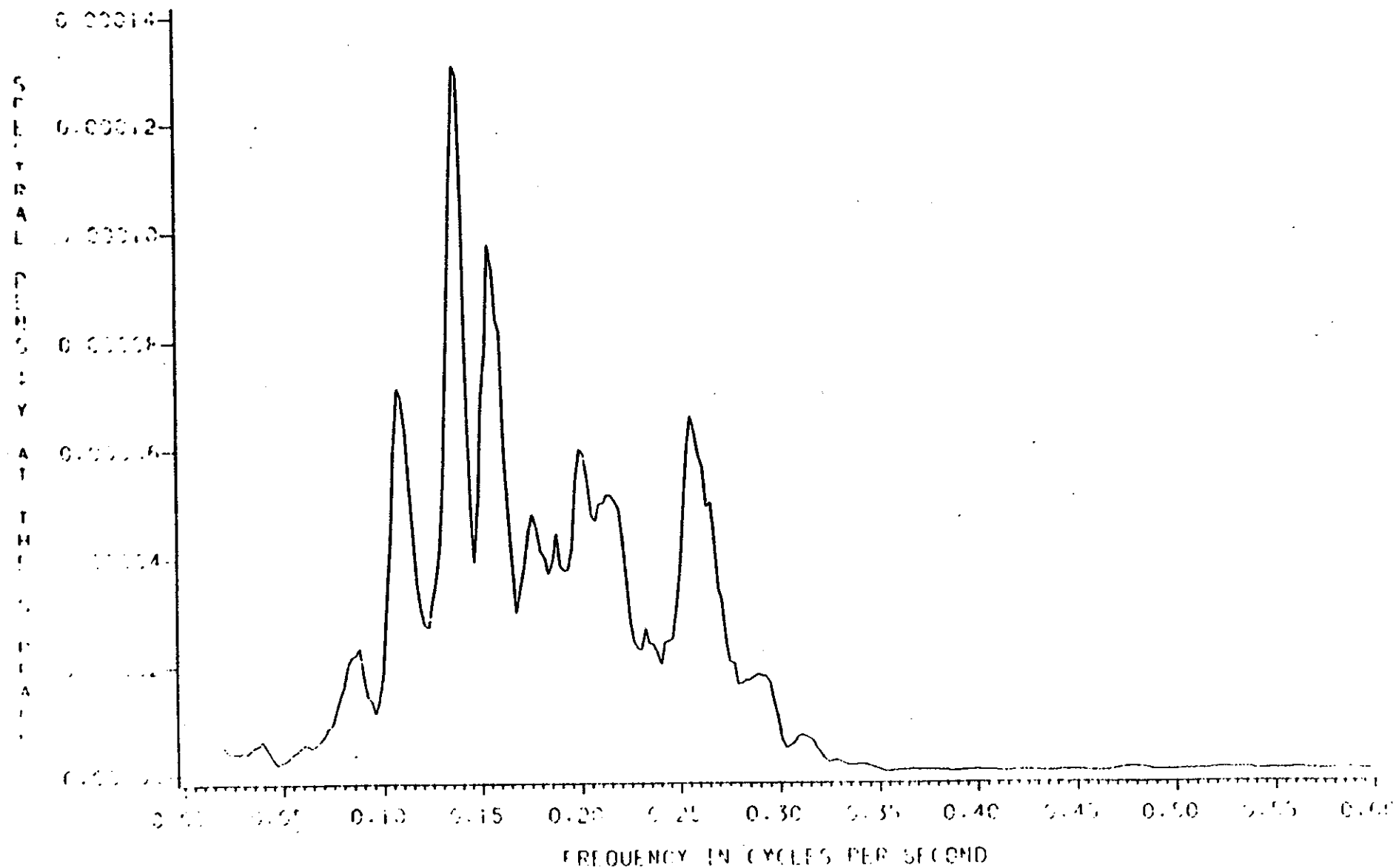
wave systems will be modified by progressive shoaling and/or sheltering induced by the bathymetry and the orientation of Clinton Harbor. The extensive shallows fronting the Harbor favor dissipation of the low frequency, long wave length waves limiting incidence to waves having periods of six to eight secs. or less. Such dissipation has been documented at other similar areas within the eastern Sound (Stone and Webster, 1977). Dissipation also affects wave height and appears sufficient to offset shoaling effects. As a result inshore wave heights seldom exceed the observed offshore maxima. The orientation of Clinton Harbor and the presence of headland shoals near Hammonasset Point and shoals and a breakwater adjacent to Hammock Point limits incidence to wave propagating from the southerly quadrant. As a result aperiodic, high energy, northeasterly storms will tend to have less effect than lower energy but more persistent systems rich in southwesterly, south and southeasterly winds.

3.4.4 Streamflow Characteristics

The hydrography of the area within and adjacent to Clinton Harbor is affected by freshwater discharge from the Hammonasset and Indian Rivers and by discharge from the more distant Connecticut River. Both systems display a regular seasonal cycle with maxima typically occurring during the spring and minima during the late summer. Representative discharge data for the Hammonasset and Connecticut Rivers are listed in Tables 1 and 2 included as Appendix A. The Indian River is not gaged. Drainage basin comparisons suggest that its discharge will equal approximately 10 to 20% of the discharge from the Hammonasset.

3.4.5 Water Column Characteristics

The seasonal cycle in air temperature, streamflow and wind
stress induces concurrent periodic variations in water column
temperature and salinity within Clinton Harbor. During an
average year water temperatures range from a low of approximately
32°F during February to a maximum of 75°F in late August. Salin-
ities range from a minimum of near 0'/oo to a maximum of approxi-
mately 29°/oo. The annual variation in salinity is essentially
coincident with the local streamflow cycle. Limited observations
during 1978 at a site just south of the entrance to the Harbor
indicate that the vertical distribution of temperature and
salinity throughout the year is essentially homogeneous and there
is little evidence of significant persistent stratification
(Ocean Surveys Inc., 1978). Given the shallow depths characteri-
zing the area similar conditions can be expected to prevail
throughout most of the Harbor.

3.5 Sediment Transport System Characteristics

Sediment distributions within Clinton Harbor represent the
resultant of interactions between available sediment supplies and
the variety of transport factors including winds, wind waves,
tidal currents, sealevel and streamflow.

Since the termination of the last period of glacial advance
approximately 15,000 years ago these factors have combined to
produce a system characterized by a moderate to high degree of
spatial and temporal variability. During the immediate post-
glacial period sea level adjacent to the eastern Sound was
approximately 125m (375 ft) below its present level and the areas

18

within the Sound consisted of series of stream-cut valleys and associated freshwater ponds. Evidence for such valleys is present at several locations adjacent to Clinton (Flint, 1971). As glacial melt progressed increasing water levels in the downstream ponds caused gradual inundation of the coastal valleys favoring accumulation of fine grained sediments and formation of freshwater swamps and bogs. Concurrently sea levels along the adjacent continental margin were rising. As this cycle progressed the stability of the freshwater lake forming within the Sound steadily decreased and at some point its eastern limit was breached and the freshwaters drained to be eventually replaced by oceanic saline waters.

This shift in status from a freshwater lake to coastal embayment significantly modified transport conditons and exposed the entire Sound to the effects of tides and tidal currents. The resultant estuarine conditions favored nearshore retention of fine-grained materials supplied from both upstream and offshore source areas. In areas where sedimentation rates were sufficient to offset the effect of advancing sea level tidal marshes formed. In many cases these marshes formed in and over areas that had previously been freshwater swamps. Soundings indicate that the marshes found along the bachshore adjacent to Clinton formed during this period and in several areas developed over relict freshwater swamp deposits (Hill and Shearin, 1970; Flint, 1971).

Concurrent with the accumulation of fine grained materials and marsh formation the combined effects of wind waves and tidal currents were resulting in segregation of coarser grained materials favoring the formation of submarine bars and subaerial

19

beach and dune systems. Materials forming these structures were derived from glacial debris introduced by meltwater runoff to form shoreline deltas or by erosion of moraine associated deposits. Structures associated with these latter deposits typically took the form of spits or downdrift structures attached to the sediment source area. In many areas the formation of spits and bars favored development of backshore lagoons where reduced energy levels served to accelerate sedimentation rates contributing to increased tidal marsh development. Observations indicate that such marsh development was established in areas significantly seaward of present day shorelines.

As sea level advanced wave attack and associated washover caused progressive shoreward migration of the spit-bar system. Initial sediment source areas were inundated and backshore marshes were in part covered by migrating sands and forced to retreat shorewards. The cycle continued until the spit-bar system encountered the edge of the more resistant uplands. At this point shoreward migration terminated or slowed substantially. The resultant material distributions merged with shore derived sediments forming some combination of pocket and/or barrier beaches and attached spits. Subsequent variations in the form of these structures now depended primarily on available sediment supplies and the extent of man-made alterations with sea level advance representing a secondary, relatively minor, determinant.

In the area of Clinton Harbor the shoreward migration of spit-bar systems contributed to the formation of Hammonasset Beach, to the spit tending north and east from Hammonasset Point,

and to the broad sand platform forming most of the Harbor bottom. Materials initially derived from erosion of several offshore morainal deposits, most probably located in the vicinity of Falkners Island and Six Mile Reef, merged with sediments supplied by the erosion of glacial till near the present day Hammonasset Point and Hammock Point. The resultant structures formed initially well seaward of the present shoreline and migrated northerly as sea level advanced. Borings indicating the presence of peat at depth suggest that this formation and subsequent migration served to inundate portions of previously formed tidal marshes. Erosion has exposed sections of this peat layer at several locations along the western limits of the Harbor.

Coincident with beachfront migration tidal marsh development along the backshore of Clinton Harbor has proceeded as a result of trapping of fine-grained sediments derived from upland source areas and offshore erosion. This latter tidally mediated source is supplemented aperiodically by materials introduced via Connecticut River streamflows. Observations indicate that portions of the Connecticut River plume intrude aperiodically into Clinton Harbor during periods of high streamflow (Garvine, 1974).

At present, sediment distributions within Clinton Harbor appear to represent a near equilibrium between sediment supply and available transport energy. These conditions, and the characteristic shallow water depths associated with them, appear to have prevailed in the area for more than 100 years. Within the offshore area this equilibrium is supported by observations obtained as part of this investigation (Taxon, 1982). Under the conditions observed the sediment-water interface throughout the

21

Harbor was typically deformed into periodic wave and tide-induced ripples and displayed significant short-term variability in textural characteristics. These observations suggest that in the absence of sea level variations, the interface is a region of zero net deposition. As evidenced by the frequency of dredging required to maintain the navigational channel this condition is not the result of insuifficient sediment supply. Given a reduction in transport energy, sufficient sediment is available to sustain measurable deposition. Discounting sediment supply, the high frequency response of the sediment-water interface can only imply maintenance of near equilibrium within the sediment transport system active within the open waters of Clinton Harbor.

Along shore, reviews of aerial photographs and available historical maps of the region indicate that a similar near equilibrium prevails. Beachfront contours display a moderate to high degree of stability and there is little evidence of significant erosion. The coastal system in the vicinity of Clinton Harbor appears dominated by a west-to-east drift of sediment governed primarily by the local surface wind wave field. On the western side of the Harbor this system favors the displacement of sediments from the vicinity of Hammonasset Point longshore, north and east into the Harbor to the vicinity of Cedar Island. Historically, this movement of sediment has resulted in accretion, particularly where shore perpendicular structures intercept longshore drift (Figure 3-3), and contributed to the progressive eastward displacement of the distal end of the spit (U.S.A.C.E., 1949).

Figure 3-3. Aerial photograph of Clinton Harbor (4-10-75) showing
west-to-east longshore movement of sediment along south
face of Cedar Island spit.

23

The extent and character of this migration appears sensitive to both sediment supply and the degree of equilibrium between the longshore transport system and outflows from the inner Harbor dominated by tidal exchange and Hammonasset River streamflow. As easterly accretion proceeds these flows erode progressively more material from the spit end so as to maintain sufficient channel capacity. Within such a system, aperiodic storm events can produce conditions in which erosion rates will be insufficient to provide the required increases in channel flow capacity. Under such conditions the volume of water trapped in within the inner Harbor will tend to induce flooding and erosion of low-lying areas along the the more landward sections of the spit. The process favors the formation of a secondary channel and the associated development of a barrier island. Data indicate that such a sequence has occurred several times within Clinton Harbor. Surveys conducted in 1891 show Cedar Island separated from Hammonasset Point by a well-defined channel called the Dardanelles (U.S.A.C.E., 1949). Materials obtained during the 1891 Federal Navigation Project were used to close the breach. By 1949 erosion had served to reopen the channel (Figure 4-4) and again materials obtained from dredging were used to close it. At present, the breach remains closed and the area appears stable and resistant to flooding and/or washover and associated erosion. Some instability is evident however, along more easterly sections of the spit where lower beach elevations prevail and dune grass growth is limited. Such areas have the potential to favor future breaching of the beach face.

Along the eastern side of the Harbor sediment displacements
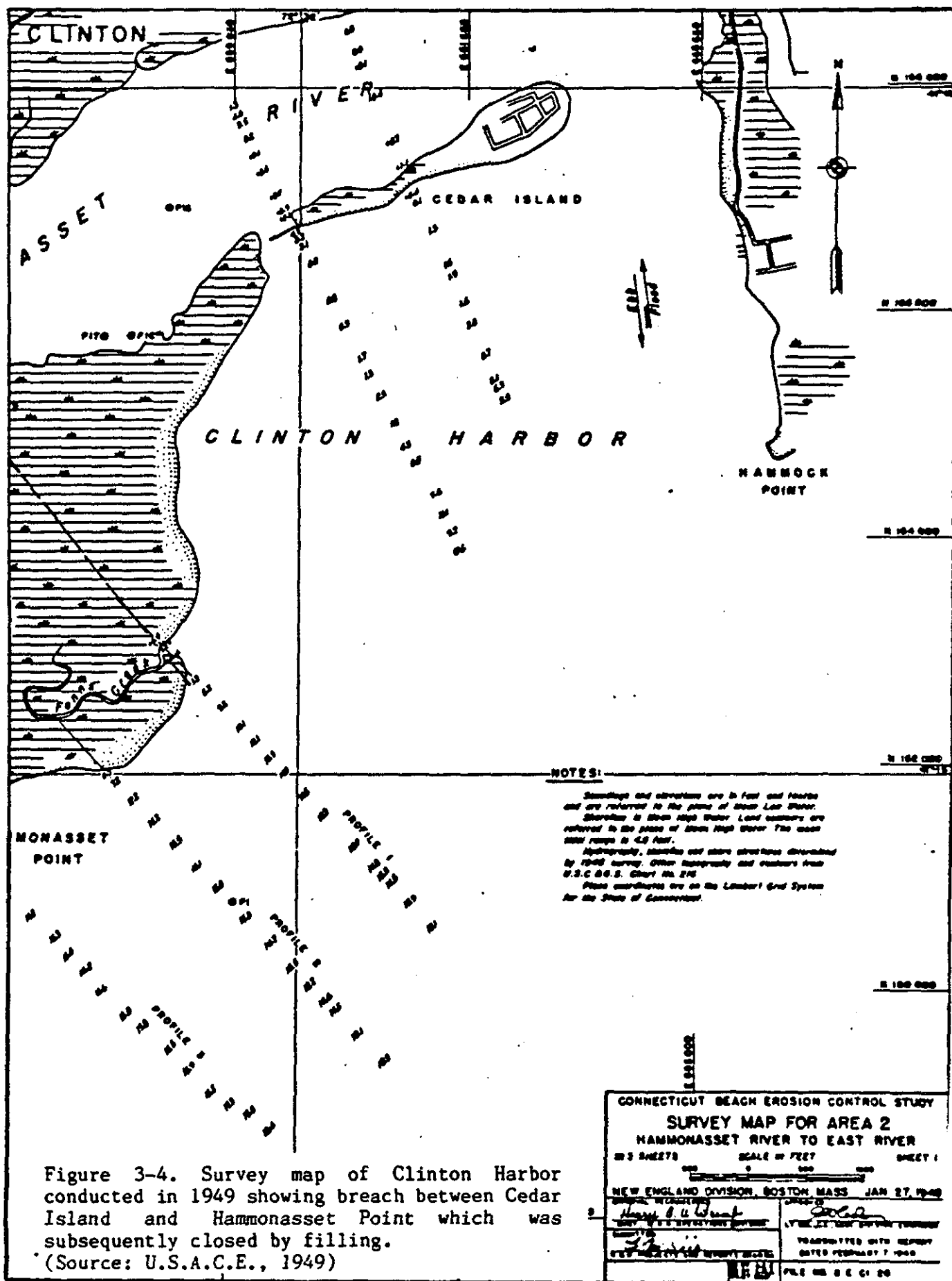
Figure 3-4. Survey map of Clinton Harbor conducted in 1949 showing breach between Cedar Island and Hammonasset Point which was subsequently closed by filling. (Source: U.S.A.C.E., 1949)

display a higher degree of spatial variability. South of Hammock Point the dominant west-to-east transport observed to the west of the Harbor prevails and sediments are displaced easterly towards Kelsey Point. To the north of the Point dominant drift directions vary from northerly near the entrance to the inner Harbor to mixed-tending-southerly at a point near the mid-section of the eastern Harbor limit. The observations indicate that a null point in longshore drift exists in this latter area suggesting that coastal transport along the eastern shore is dominated by wave systems rich in southwesterly components. As in the case of the western limit of the Harbor there is no indication of significant long-term erosion.

In summary, the sediment transport system active within Clinton Harbor represents the resultant of a variety of processes that have shaped and modified the region since the termination of the last glacial advance. At present, a near equilibrium appears to prevail between local sediment supplies and incident transport energy. Within the backshore areas fine grained materials supplied by upland drainage and offshore transport are accumulating at rates sufficient to maintain the viability of local tidal marshes and to favor infilling of stream courses and/or navigational channels. Within the open waters of the Harbor coarser grained materials derived from the erosion of local headlands or offshore relict glacial deposits blanket the Harbor bottom and the bordering shorelines. Transport of these materials is governed primarily by the incident surface wave field with tidal currents playing a secondary, albeit important, role. Observa-

tions of sediment-water interface response and reviews of historical data suggest that the sediment distributions within the Harbor are in near equilibrium with the available transport energy. It is within the context of this equilibrium system that the impacts of the proposed DMCF must be evaluated.

4.0 EVALUATION OF IMPACTS

4.1 General

As described in Section 3, the sediment transport system active within Clinton Harbor is the resultant of interactions between local tidal currents, wind waves, and available sediment supply. The nearshore currents existing in Clinton Harbor and possible changes in current patterns and magnitudes due to DMCF placement were addressed in the previous report (Taxon, 1982). Here, primary emphasis will be placed on the influence of the DMCF on the local surface wave field and sediment supply.

The DMCF has the potential to perturb the wave field within Clinton Harbor by: (1) modifying wave refraction patterns, (2) inducing significant wave diffraction, and/or (3) altering wave reflection characteristics along the harbor margin. Each of these factors will be considered separately. Section 4.2 presents results and discussion of wave refraction analyses for various wave field conditions and tidal states. Section 4.3 summarizes the analysis of probable wave diffraction patterns associated with the DMCF. Section 4.4 provides an assessment of wave reflection effects. Potential impacts of the proposed DMCF on sediment supply are primarily related to the extent to which the structure interrupts or re-routes the longshore drift of sediment. A secondary impact concerns the relationship between DMCF placement and overall stability of the spit in the vicinity of Cedar Island. Both of these factors are discussed in Section 4.5.

4.2 Wave Refraction Analysis

4.2.1 Overview

Wave-induced sediment transport varies primarily as a function of the directional characteristics and energy content of the incident wave field. Within the nearshore zone both of these factors will be affected to some extent by shoaling induced refraction. The degree of refraction experienced by an inshore propagating deepwater wave and ultimately determination of the extent to which the proposed DMCF contributes to this process can be evaluated by examining wave ray patterns associated with selected wave groups. Wave rays (i.e. perpendicular connectors to incoming wave fronts) provide ready visual indication of rotation in wave front orientation and the spatial character of associated wave energy induced by local water depth gradients.

Tracing of wave rays from deep water to the shore is a technique made practical by the availability of general purpose computer programs which rapidly accomplish the numerous repetitive computations. The existing bathymetry of an area is stored in computer memory and rays associated with selected systems of deepwater waves are traced through this depth field to their points of impact on shore. The resultant pattern provides direct indication of the angle of incidence of the wave system at the shoreline and a qualitative measure of the importance of longshore transport within the the local sediment transport system. In addition, if it is assumed that the energy between progressive waves is constant, examination of the degree of ray convergence permits identification of those areas of the coast most subject to significant wave attack.

29

The method of wave ray tracing used for this study is that developed by Dobson (1965) and is based on linear wave theory (Wiegel, 1964; Kinsman, 1965). Although the method assumes no energy loss due to bottom friction, it has been shown to provide reasonable results for systems characterized by gradual shoaling. As noted such conditions appear to prevail within and adjacent to Clinton Harbor.

4.2.2 Application of Dobson's Wave Refraction Analysis

Application of Dobson's wave refraction analysis method required establishment of the bathymetric and offshore wave characteristics. Bathymetric data were obtained from NOAA Chart 12374 (Duck Island to Madison Reef). Figure 1-1 shows the area upon which a 31 by 44 grid, oriented north-south, was applied. Each cell is 375 feet on a side. Figure 4-1 shows MLW water depths assigned to the grid. Width of the grid area in the E-W direction is 2.2 miles and 3.1 miles in the N-S direction. Total area of the grid is 6.8 sq. mi. The southern boundary of the grid is located about 1 mile north of the Sixmile Reef deep water wave data collection station.

Environmental data appropriate to the Clinton Harbor wave analysis include the following:

o Wave period: To cover the typical spectrum of offshore waves, four periods were assessed - 3, 6, 9, and 12 seconds. Since the analysis is based on the linear theory only a single initial wave height - taken as two feet - need be applied.

o Direction of advance: Three directions of wave advance were

30

Fi   4-1. Water de   ssigned to wave ray grid.

assessed corresponding to the predominant fetch exposures at the site. These directions included 135°, 180°, and 225° measured from North (i.e. SE, S, and SW).

o Tide level: Three tide level conditions were assessed including: (1) Mean Low Water (MLW); (2) MLW + 3 feet; and (3) MLW + 8 feet, taken as a storm surge condition with a probable recurrence interval of more than once in 10 years (U.S.A.C.E.,1973).

4.2.3 Results of Wave Ray Tracing

The Dobson wave ray model proved useful in determining the extent of DMCF exposure to wave attack under the assumed environmental conditions, summarized as follows:

A. Wave Penetration

For each of the conditions tested, shoaling effectively dissipated the longer period deep water waves (i.e. 9 seconds and larger) do not penetrate to the DMCF site due to encroachment on a nearshore shelf defined by approximate depths of 20 to 30 feet. Figures 4-2(a) (12-second waves at MLW) and 4-2(b) (9 second waves at MLW) illustrate this offshore shoaling effect which for these waves occurs regardless of normal tide level. During storms surge conditions the 9-second waves reach into the harbor. The area affected by 6-second waves varied as a function of tidal state. The 6-second waves from the south barely penetrate to the 6 ft depth contour at MLW (Figures 4-2(c) & (d)), penetrate to the DMCF at normal high tide (Figure 4-2(e)), and penetrate into the DMCF area during the storm surge tidal condition (Figure 4-2(f)). The 3-second waves display significantly less sensitivity to tidal state, penetrating to the DMCF area under all tidal

conditions (Figures 4-2(g),(h),(i)).

For waves from the southwest, the Hammonasset Point headland protects the DMCF from direct wave attack although the 9 second waves during storm surge conditions do penetrate to the harbor area (Figure 4-3(a)). Large period waves (i.e. 9 seconds and larger) from the southeast do not penetrate to the DMCF site (Figure 4-4(a)).

B. Wave Refraction

The analytical results indicate that for each of the periods tested, the depth variations in and adjacent to Clinton Harbor cause significant refraction of the incoming waves. In deepwater, 6,9, and 12 second waves initially advancing from the southwest and southeasterly directions are progressively rotated and display similar northerly advance in the area immediately offshore of Clinton (Figures 4-3 (a),(b),(d),(f) and 4-4 (a)-(c)). The shorter period 3 second waves maintain their initial direction of propagation until inshore of the 20 ft depth contour (Figures 4-3(h) and 4-4(e),(g)).

Refraction effects are particularly evident in the vicinity of Hammonasset Point and adjacent to the Kelsey Point Breakwater (Figures 4-2(a) to (c), 4-3 (a)&(b), 4-4(a)). Both areas are characterized by significant ray convergence and occasional crossing of rays or caustics and appear to be zones of high or focussed wave energy. Between these points, refraction is less pronounced and northward propagation proceeds with only minor wave front rotation into the vicinity of the 20 ft depth contour. Except for waves from the southwest, inshore of this point, wave

rays display increasing divergence as wave fronts rotate and become progressively more shore parallel.

Waves from the southwest are also subject to refraction onto the Hammonasset Point headland but those which get past the headland curve into the harbor and approach Clinton Harbor from a more southerly direction. This effect is shown Figures 4-3 (a)-(g). The wave ray simulations indicate that SW waves tend to focus to the center of the harbor but for most conditions, the focus zone misses the DMCF and would not be influenced by DMCF placement (Figures 4-3 (c),(e),(g)). The low period waves from the southwest are not strongly refracted once past the headland and travel across the harbor mouth (Figures 4-3 (h),(i)).

For waves from the south, wave refraction effects are well-illustrated in Figures 4-2(a) (12 second waves), 4-2(b)(9 second waves), and 4-2(c) (6 second waves). Low period waves from the south (e.g. 3 second waves) are not strongly refracted until they encounter shallow water in the harbor (Figures 4-2 (g),(h),(i)).

Waves from the southeast are in part blocked by the Kelsey Point breakwater (Figures 4-4 (a),(b),(c)). As noted, long period waves from the southeast are subject to shoaling before reaching the DMCF site (Figure 4-4 (a)). The shorter period waves (e.g. 3 seconds) at the higher tide levels travel directly to the DMCF site (Figures 4-4 (b) & (c)).

Placement of the proposed DMCF along the western margin of the Harbor (Figure 2-1) will have no direct effect on refraction of the incoming waves. With the exception of the area immediately adjacent to the toe of this structure, DMCF placement will not

34

serve to modify regional depth contours and as a result pre- and post-project factors affecting refraction should be identical. Along the base of the structure, progressive shoaling will be induced by the slope of the dike and the associated toe wall (Figure 2-2). Within this area extending approximately 15 to 20 ft seaward from the dike at mean low water, waves tend toward alignment with the orientation of the dike. Best alignments should be realized along the southern-most segment of the dike with angularity along the the remaining two segments becoming progressively more obtuse with distance into the Harbor. Along each segment this refraction will serve to reduce the angle of incidence between the incoming waves and the face of the dike below that inferred by simply superimposing the DMCF on the pre-project wave refraction patterns (as shown on the wave ray figures). This angularity becomes important within consideration of DMCF-wave interactions particularly wave reflection associated impacts.

4.3 Wave Diffraction Characteristics

Diffraction associated with the shoreward propagation of a surface wave field is typically produced by the interaction between waves reflected from a structure in the wave path and those effectively "generated" by the structure and propagating radially from its tip. The best examples of such a process are typically associated with shore-parallel, emergent breakwaters either acting singly or in groups. Waves encountering such a structure are in part reflected along its face, and in part passed by the tip. At the tip the passage of the incoming wave

35

favors generation of a second wave train propagating radially from the tip. The interaction between these two wave trains and the associated constructive and destructive interference produces a complicated wave pattern within the area in the lee of the structure. Such diffraction can result in significant wave energy within the supposed "shadow-zone" of the breakwater affecting the overall sheltering ability of the structure and offshore and coastal sediment transport.

Reviews of preliminary drawings indicate that the proposed DMCF has minimal potential for producing significant wave diffraction. The shore-attached, segmented dike (Figure 2-2) provides no plan discontinuity sufficient to support "tip generation" and the associated radially propagating wave trains. On occasion minor propagation may occur at the segment boundaries but the energy associated with the resultant waves is expected to be small and negligible in comparison to that associated with the waves produced by simple reflection.

4.4 Wave Reflection

The impervious nature and relatively steep slope characterizing the proposed DMCF dike (Figure 2-2) favor reflection of some fraction of the incident wave energy. At the proposed slope of approximately 21° empirical data indicate that approximately 20 to 30% of the incoming energy would be reflected (Wiegel, 1964). The ultimate amount depends in large part on the composition of the materials forming the face of the dike. Attenuation is increased by using coarser-grained materials and decreased for the finer-grained.

The direction of propagation of the reflected wave will vary as a function of the angle of incidence between the incoming wave field and the face of the dike. The wave refraction analyses, discussed above, suggest that along the southern-most segment of the dike under most conditions reflections will be essentially normal to the dike face inducing an offshore propagating wave train and potentially favoring formation of a standing wave system. Along the southeastern segment of the dike, the oblique angle of incidence results in a more complicated wave reflection pattern. For waves propagating from the south and southeast approaching the wall at angles ranging from perpendicular to approximately 45°, simple reflection will prevail with the angle of reflection equalling the angle of incidence. Under these conditions incoming wave energy will in part be reflected to the north and east into the Harbor (Figure 4-5). For waves approaching from the southwest, at generally lower angles of incidence than the south and southeasterly waves, reflection from the dike may result in the generation of two wave trains, one propagating normal to the wall and a second propagating along the angle equal to the angle of incidence. The interaction of these two wave trains results in a complicated surface wave pattern with a moderate degree of temporal variability. The resultant direction of energy propagation remains, however, primarily to the north and east. Finally, on the northeastern segment of the dike, wall orientation at near right angles to the majority of the incoming waves favors minimal reflection with the dike serving primarily as a dissipative lateral boundary and a partial guide leading waves shoreward.
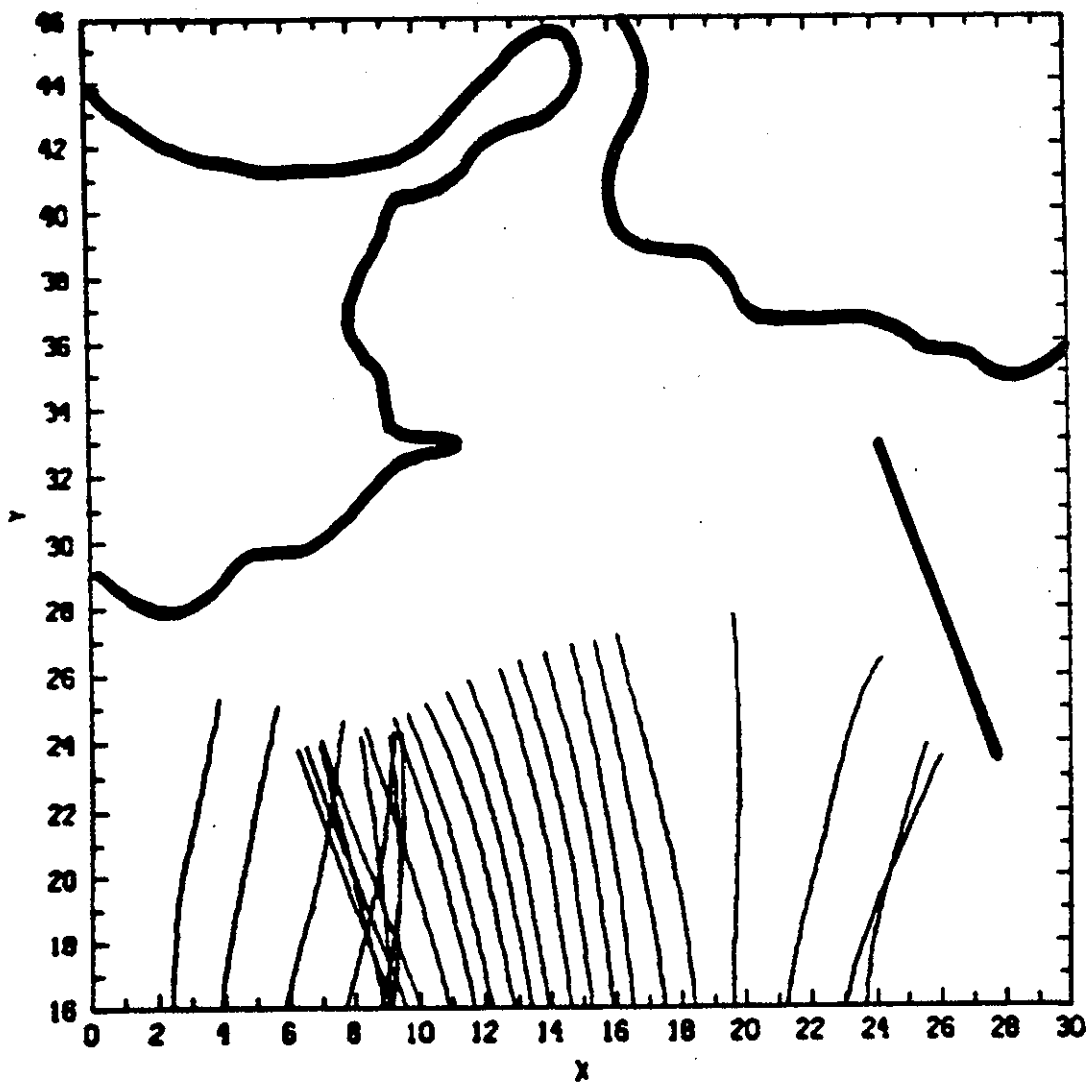
Figure 4-2 (a). Wave ray tracing: Waves from south.
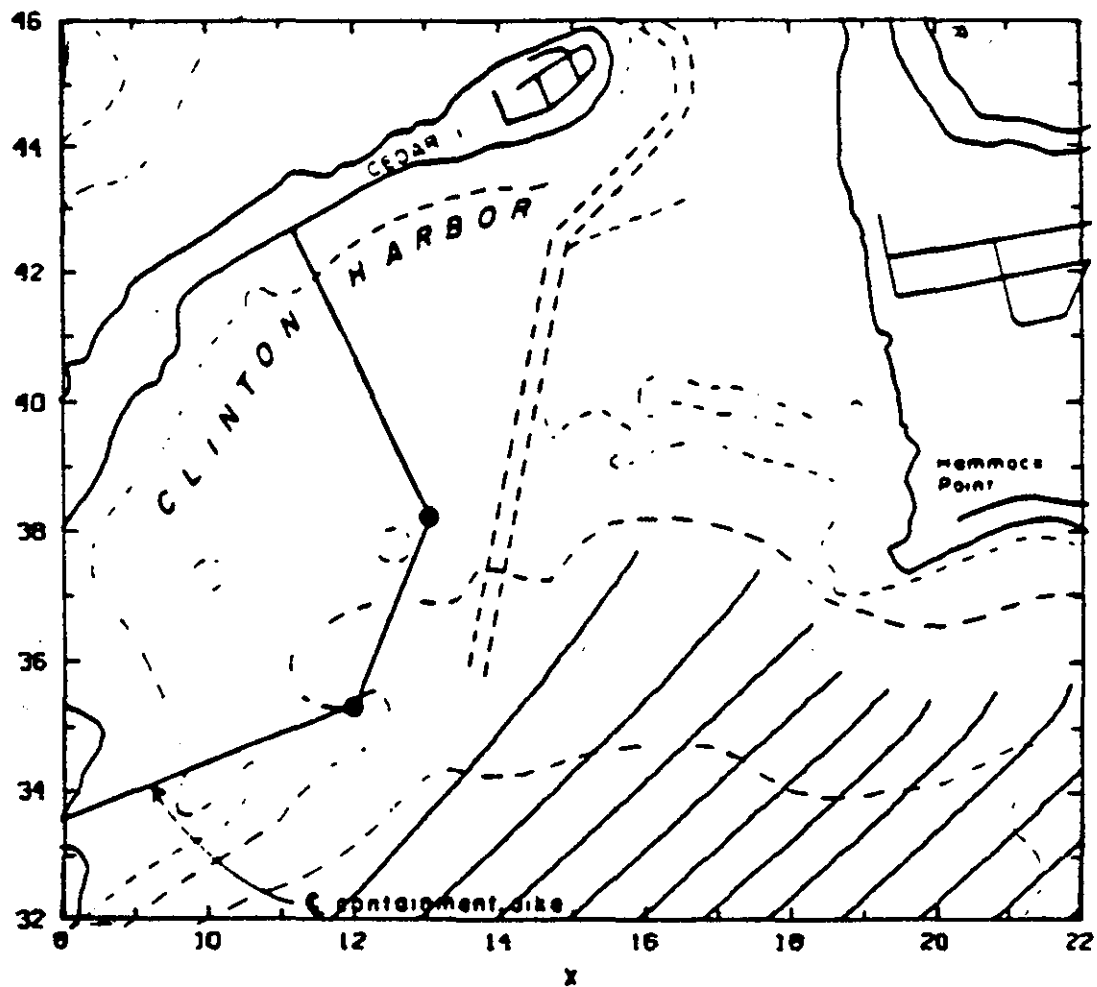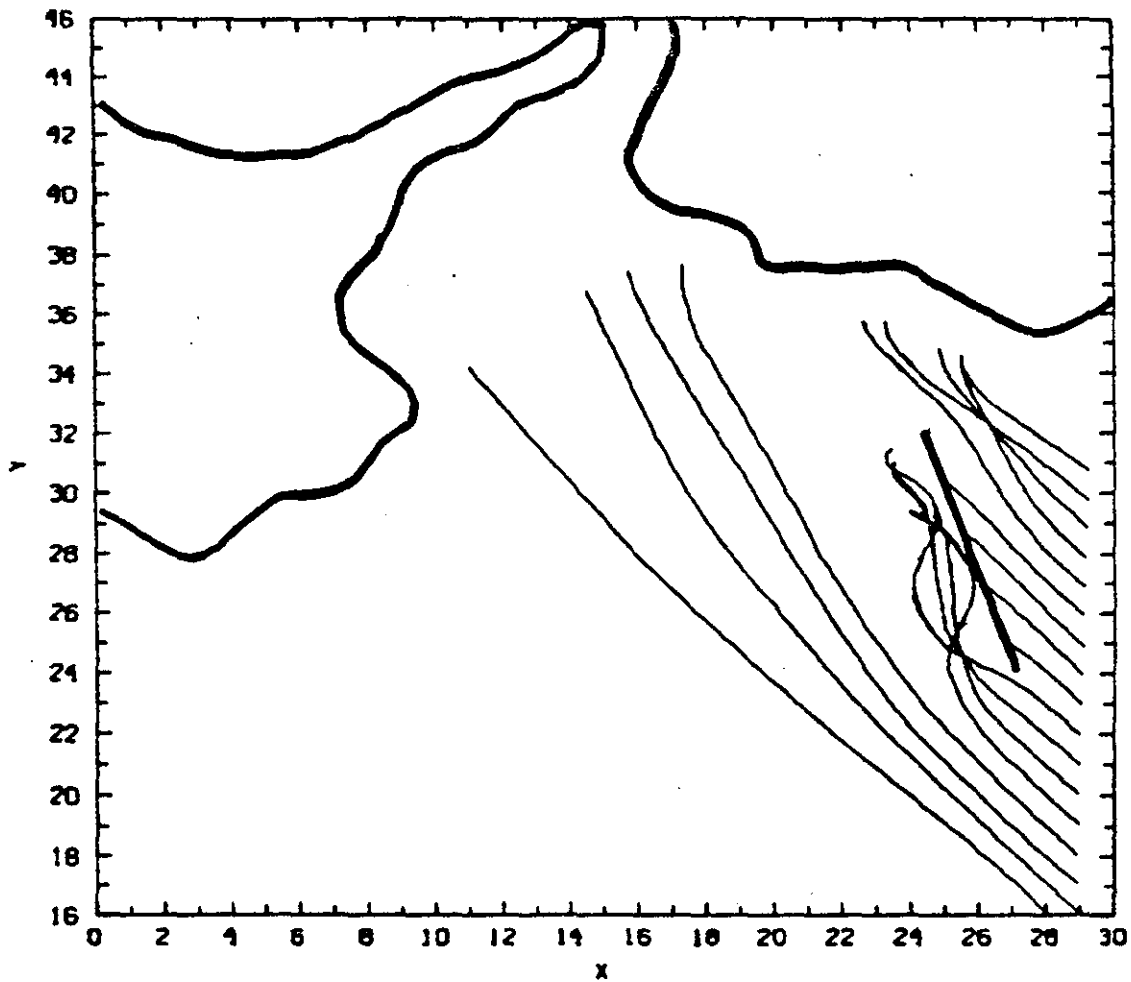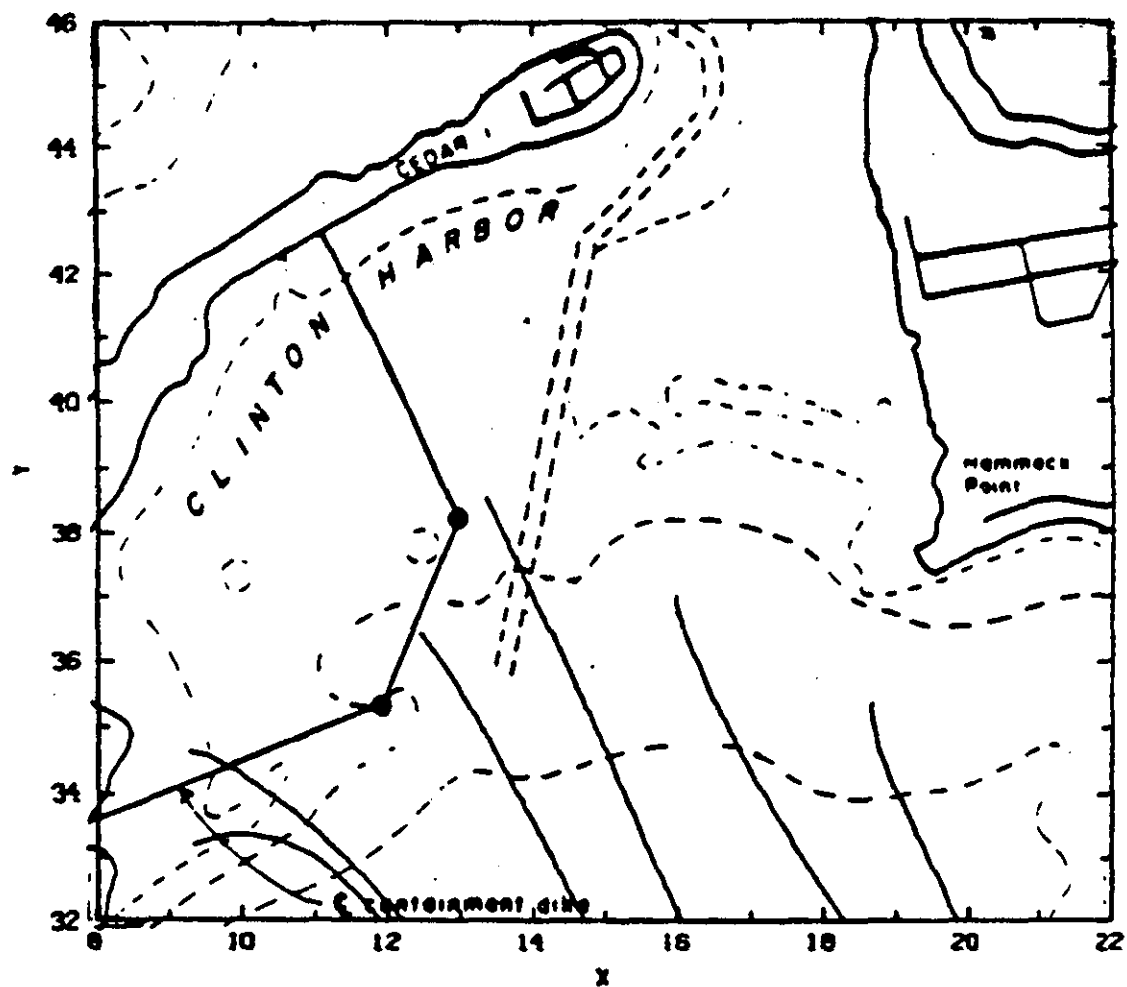Wave period 12 secs.
Mean low water + 0 feet.
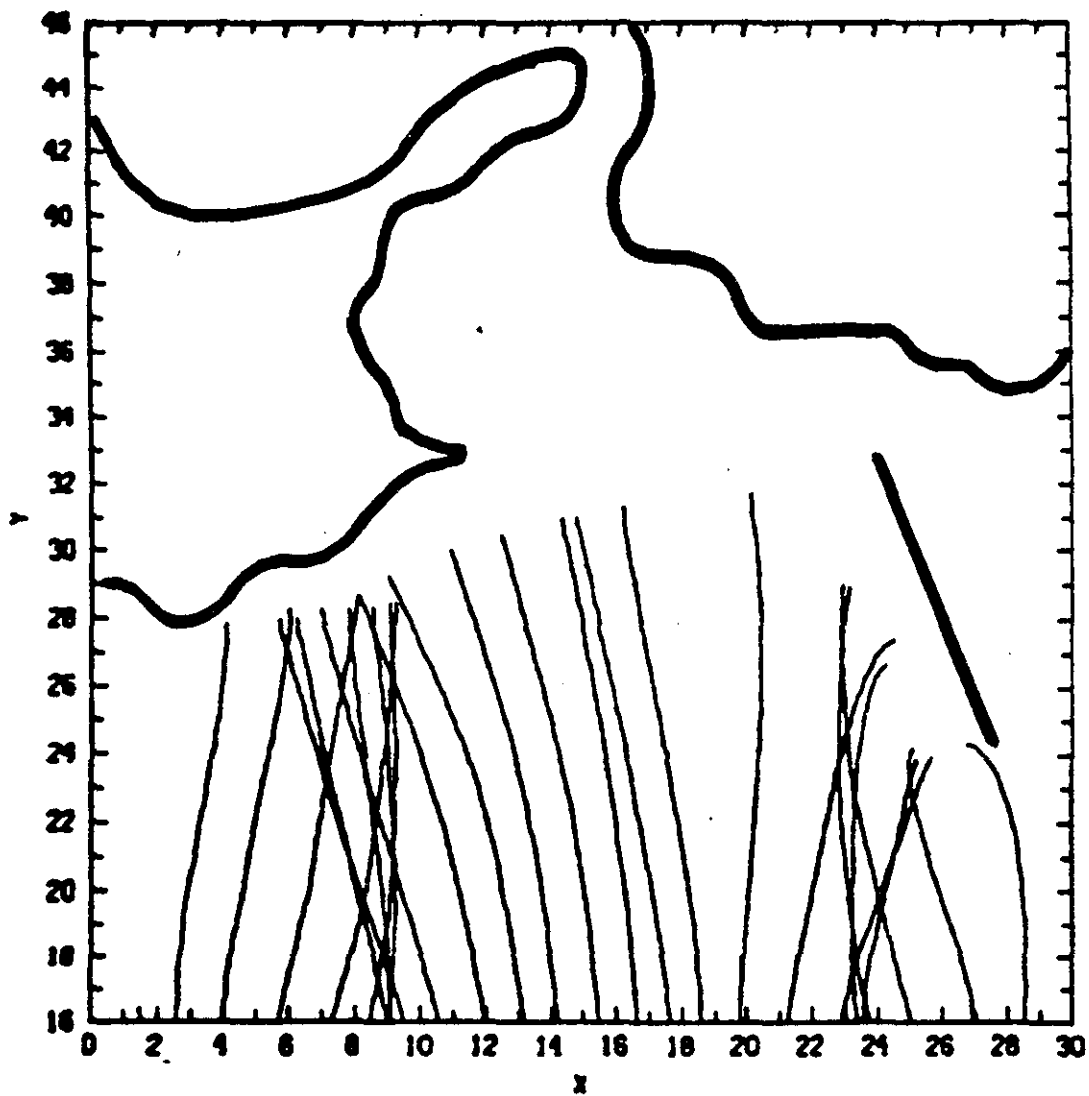
Figure 4-2 (b). Wave ray tracing: Waves from south.
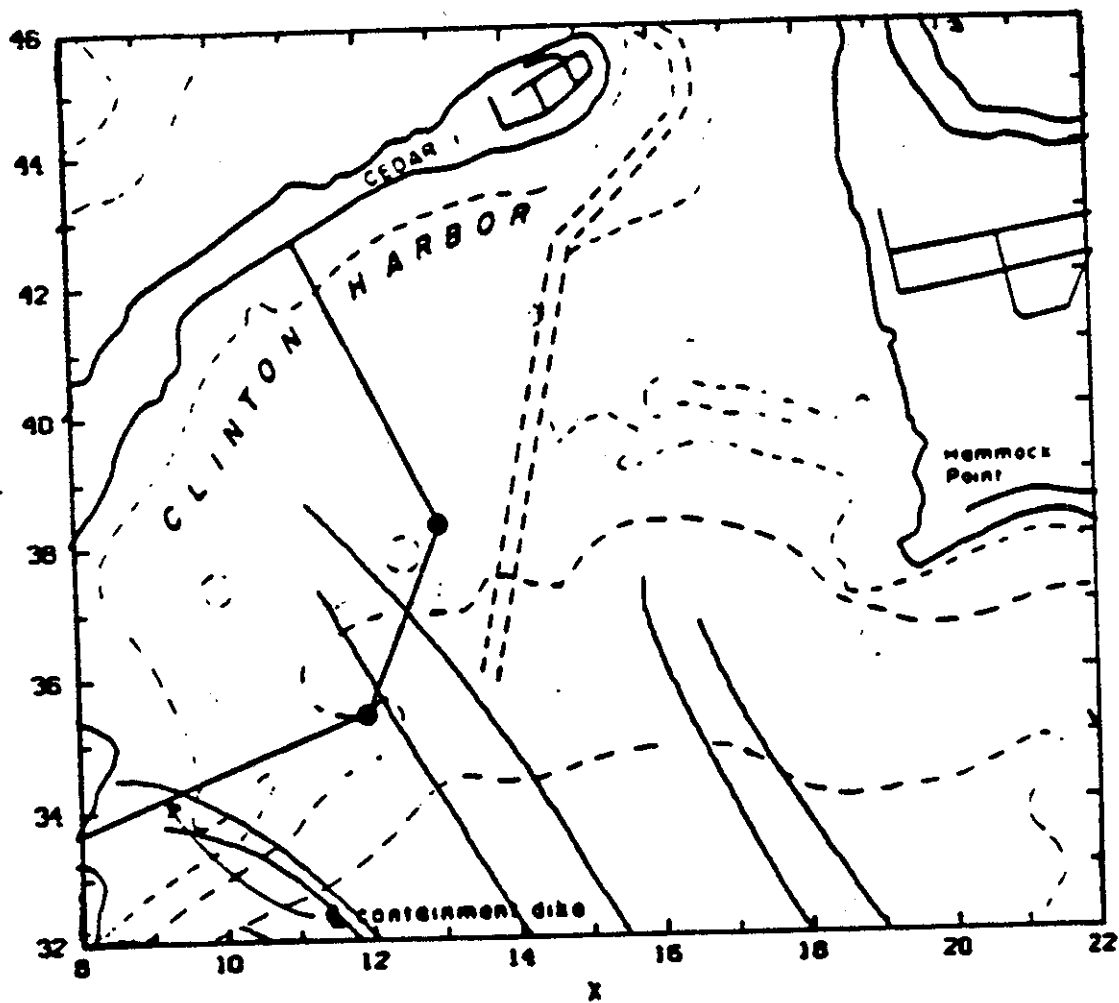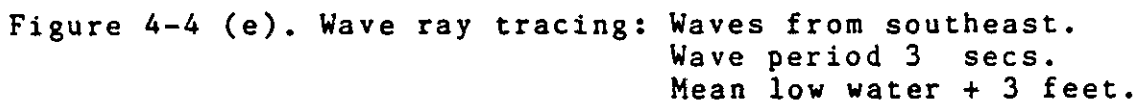Wave period 9 secs.
Mean low water + 0 feet.
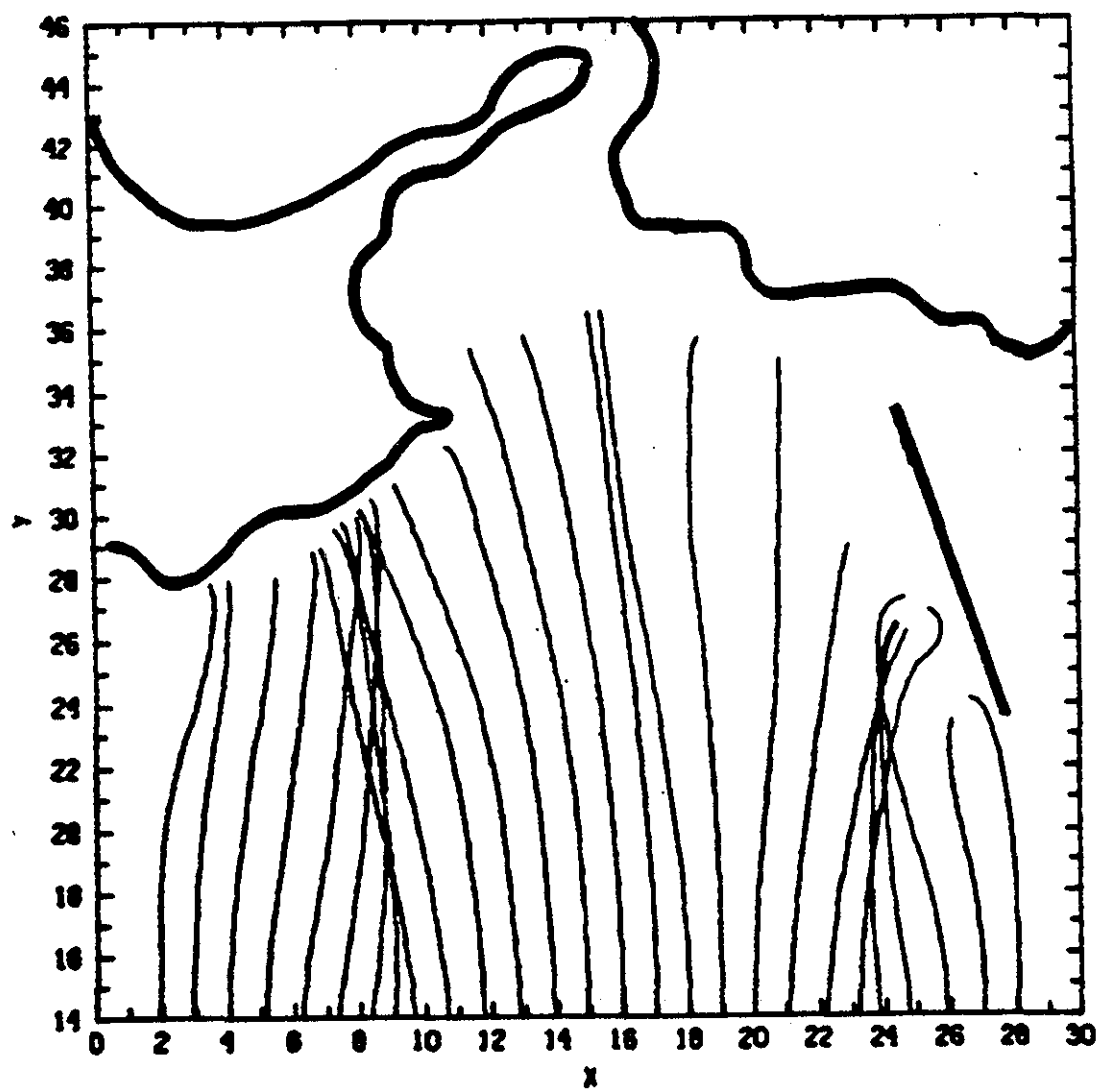
Figure 4-2 (c). Wave ray tracing: Waves from south.
Wave period 6 secs.
Mean low water + 0 feet.
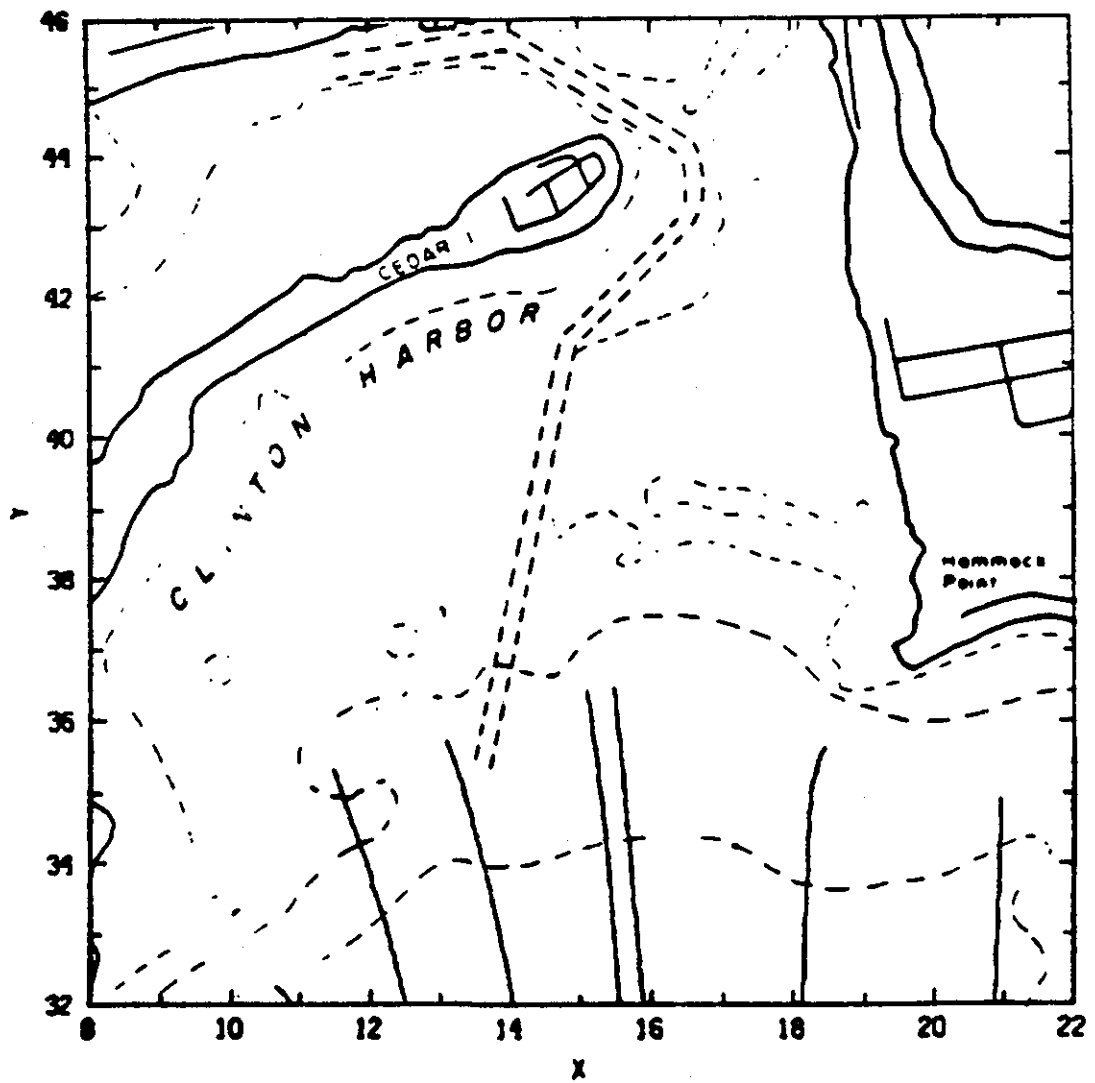
Figure 4-2 (d). Wave ray tracing: Waves from south.
Wave period 6 secs.
Mean low water + 0 feet.
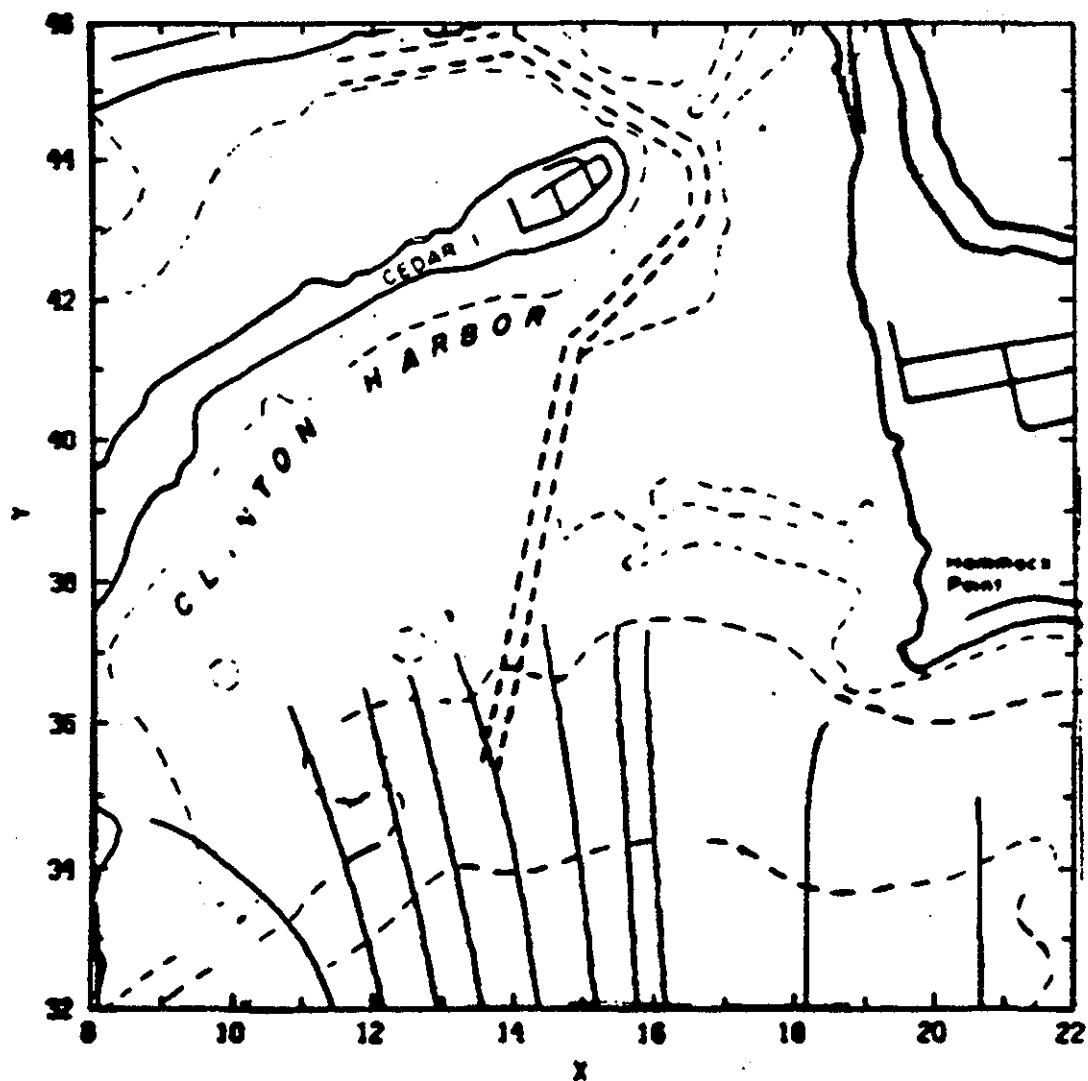
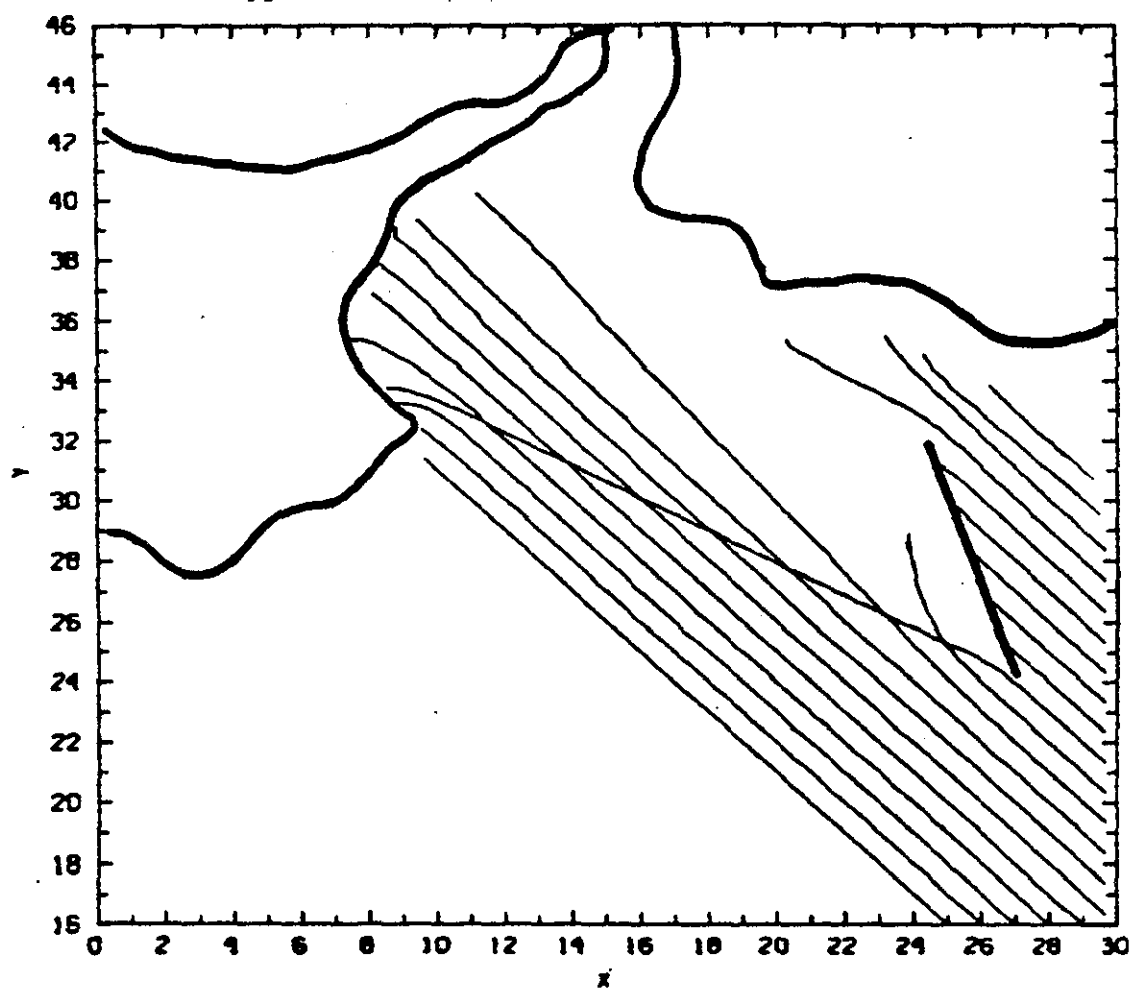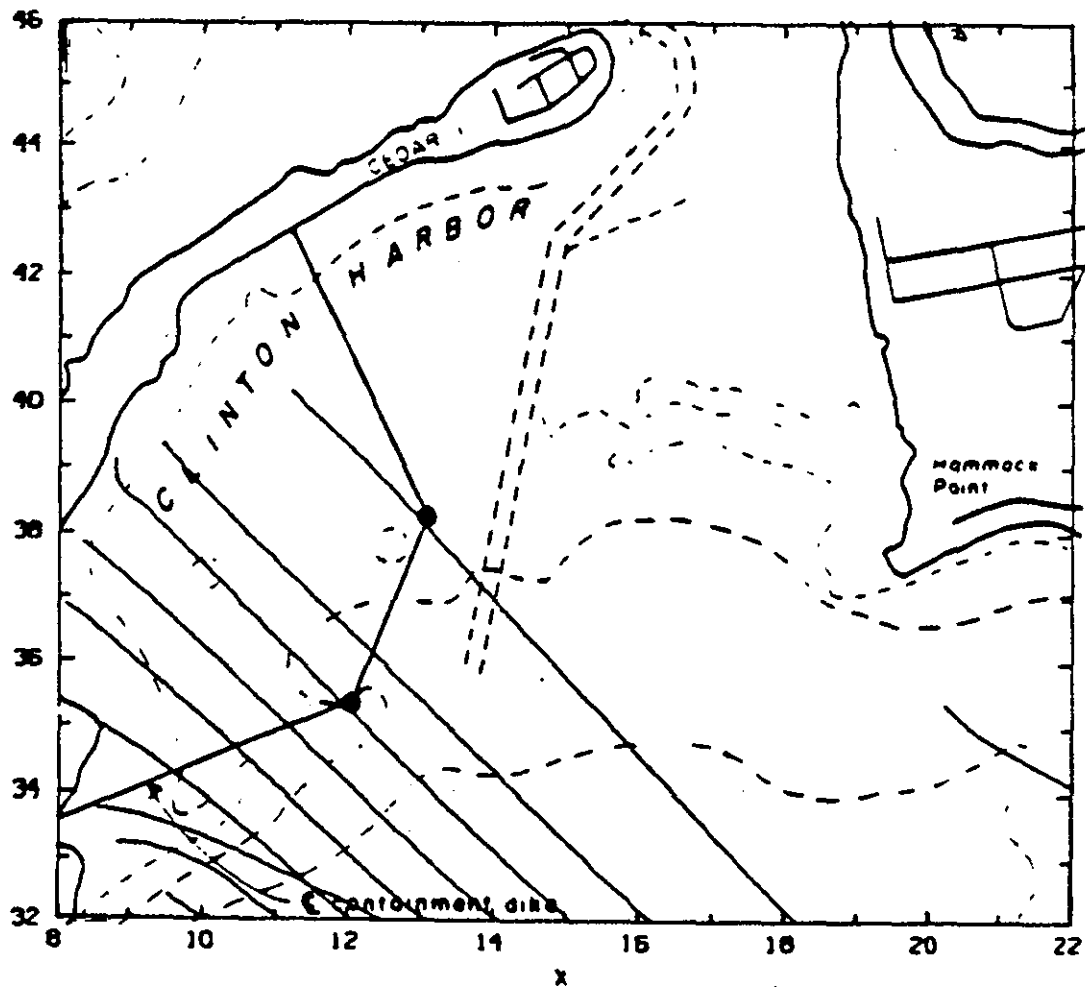Figure 4-2 (e). Wave ray tracing: Waves from south.
                                Wave period 6 secs.
                                Mean low water + 3 feet.
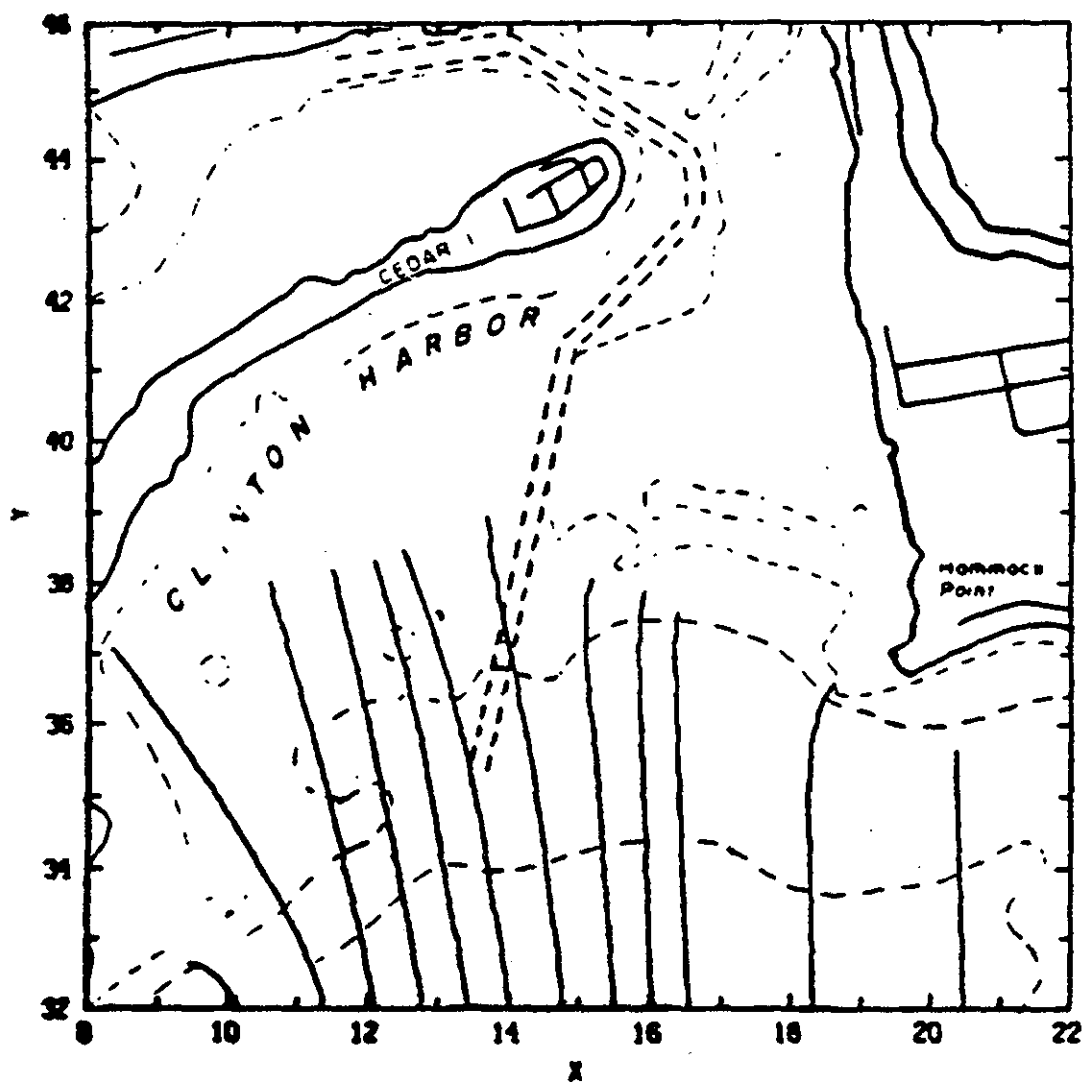
Figure 4-2 (f). Wave ray tracing: Waves from south.
Wave period 6 secs.
Mean low water + 8 feet.
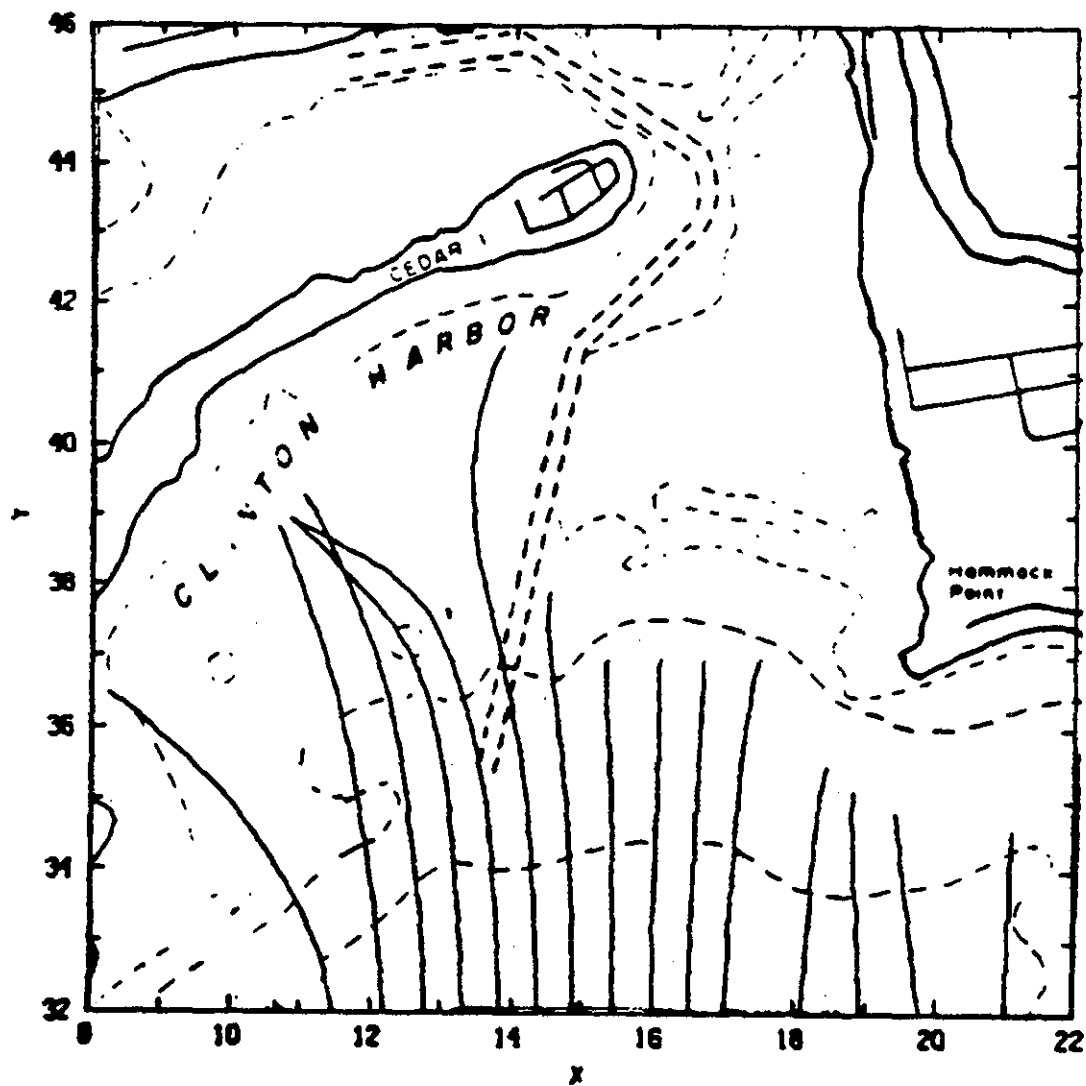
Figure 4-2 (g). Wave ray tracing: Waves from south.
Wave period 3 secs.
Mean low water + 0 feet.
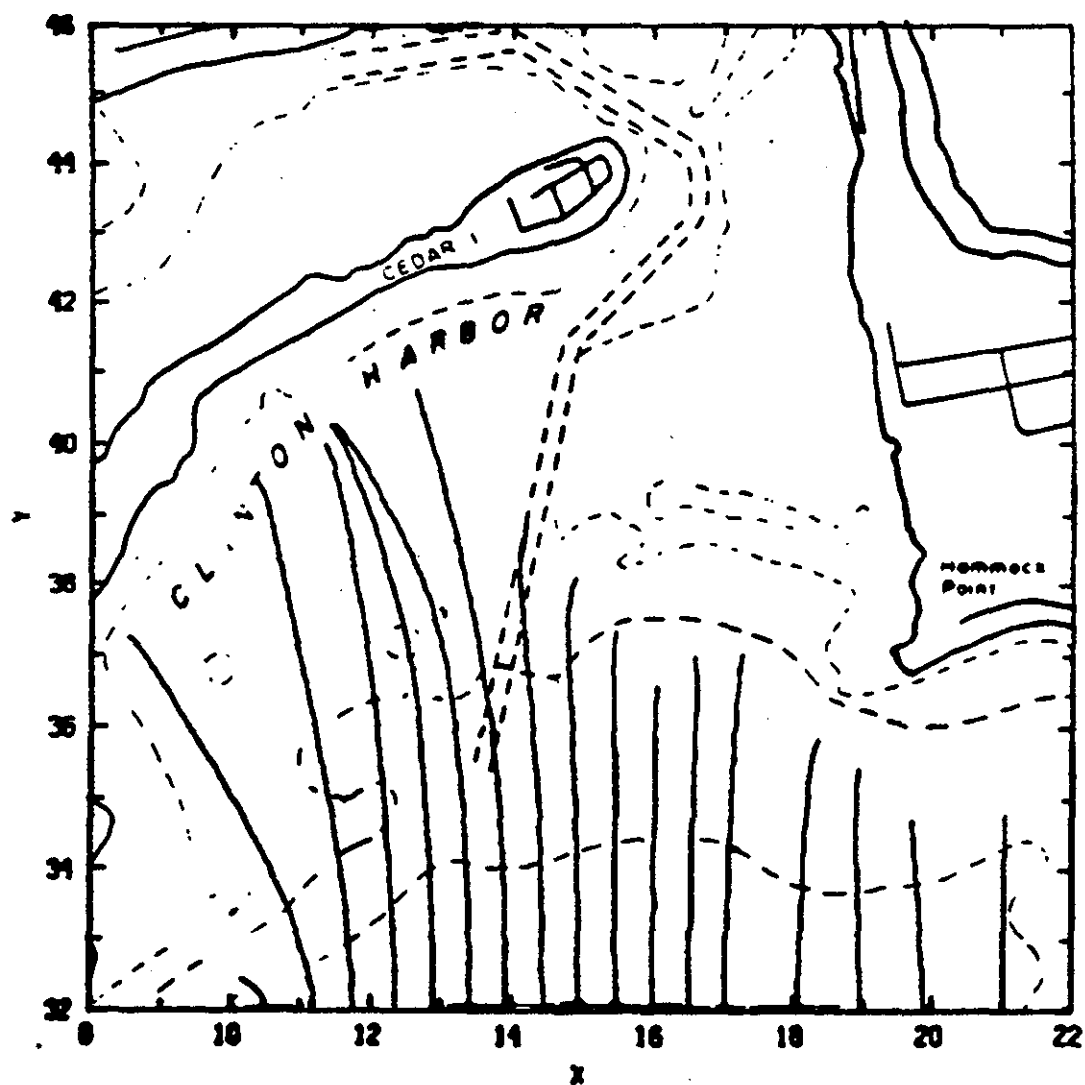
Figure 4-2 (h). Wave ray tracing: Waves from south.
Wave period 3 secs.
Mean low water + 3 feet.
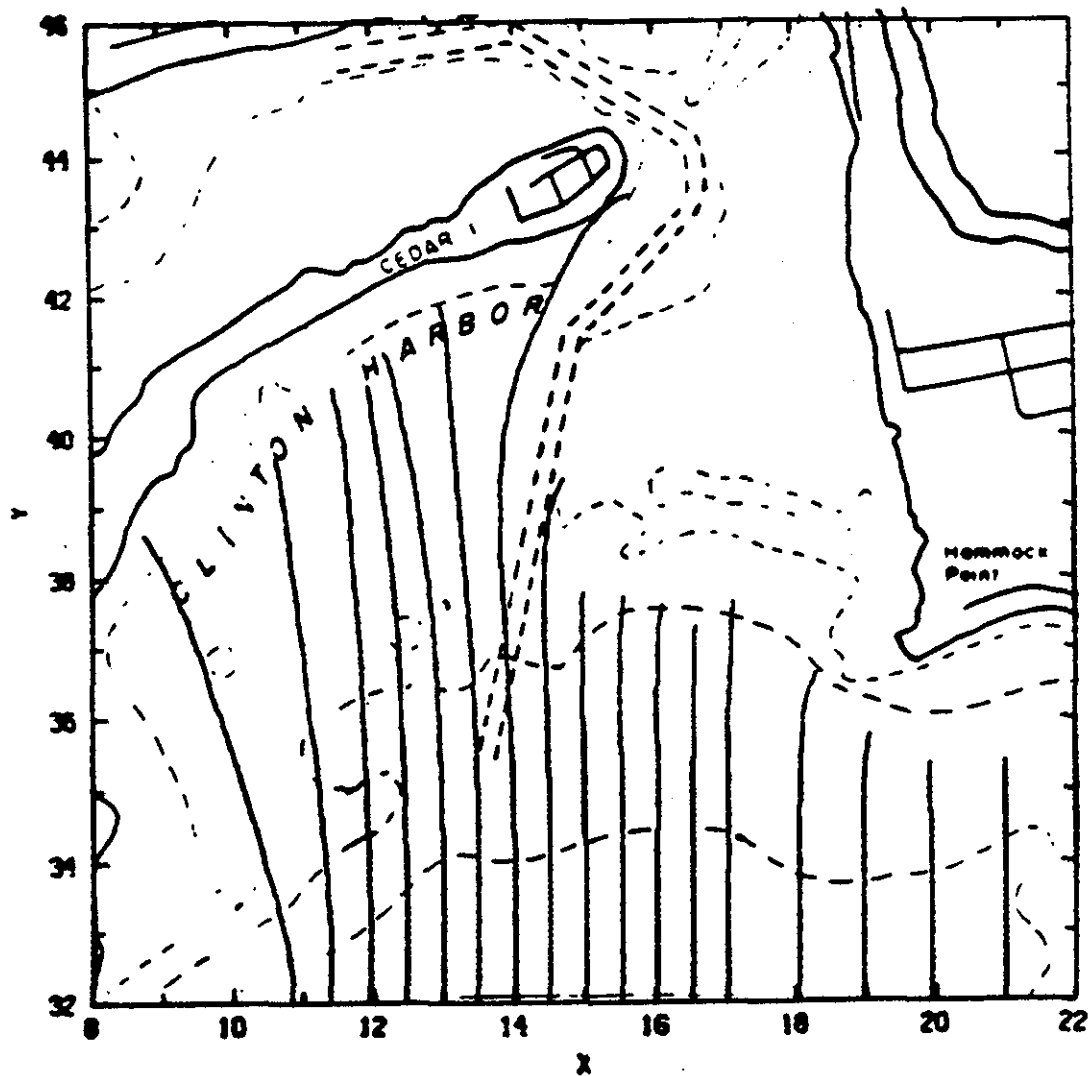
Figure 4-2 (i). Wave ray tracing: Waves from south.
Wave period 3 secs.
Mean low water + 8 feet.
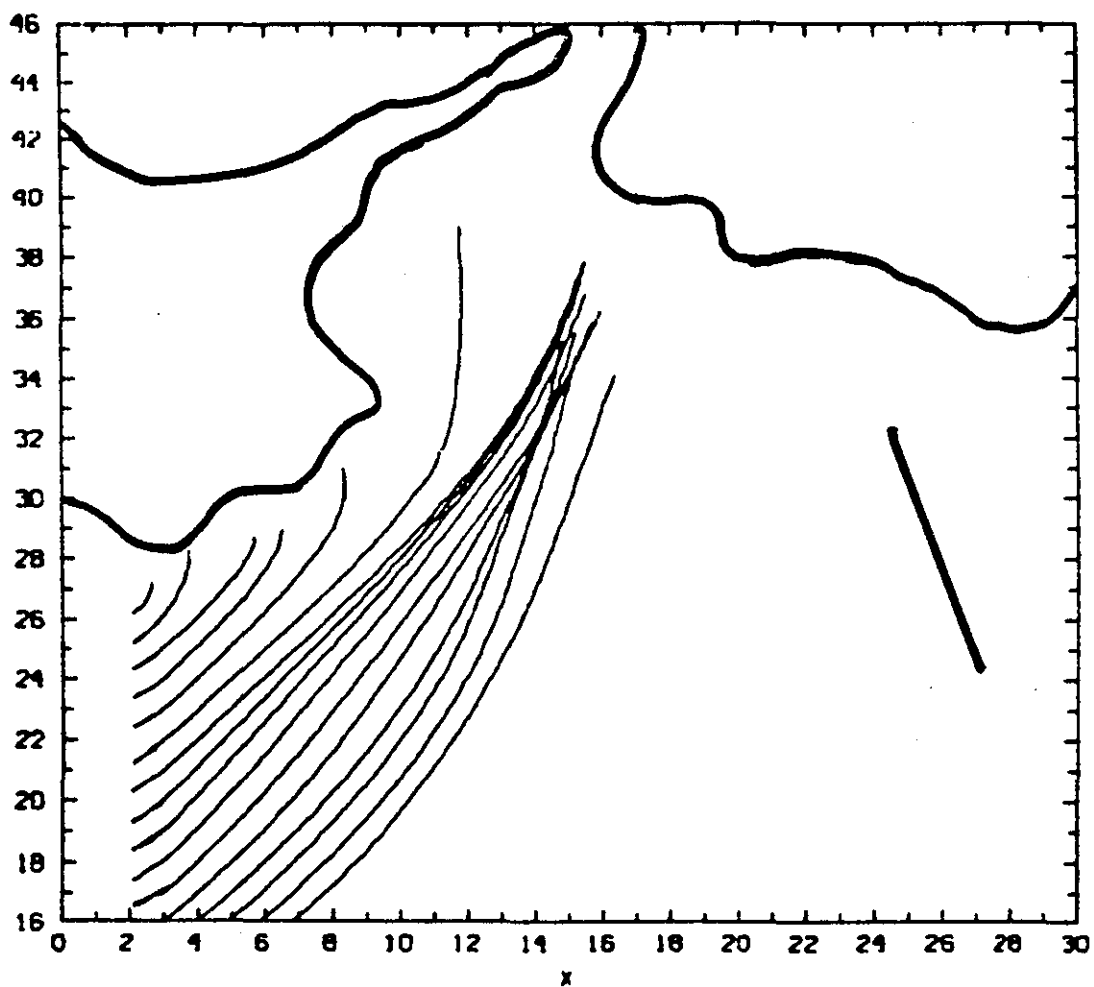
Figure 4-3 (a). Wave ray tracing: Waves from southwest.
Wave period 9 secs.
Mean low water + 8 feet.
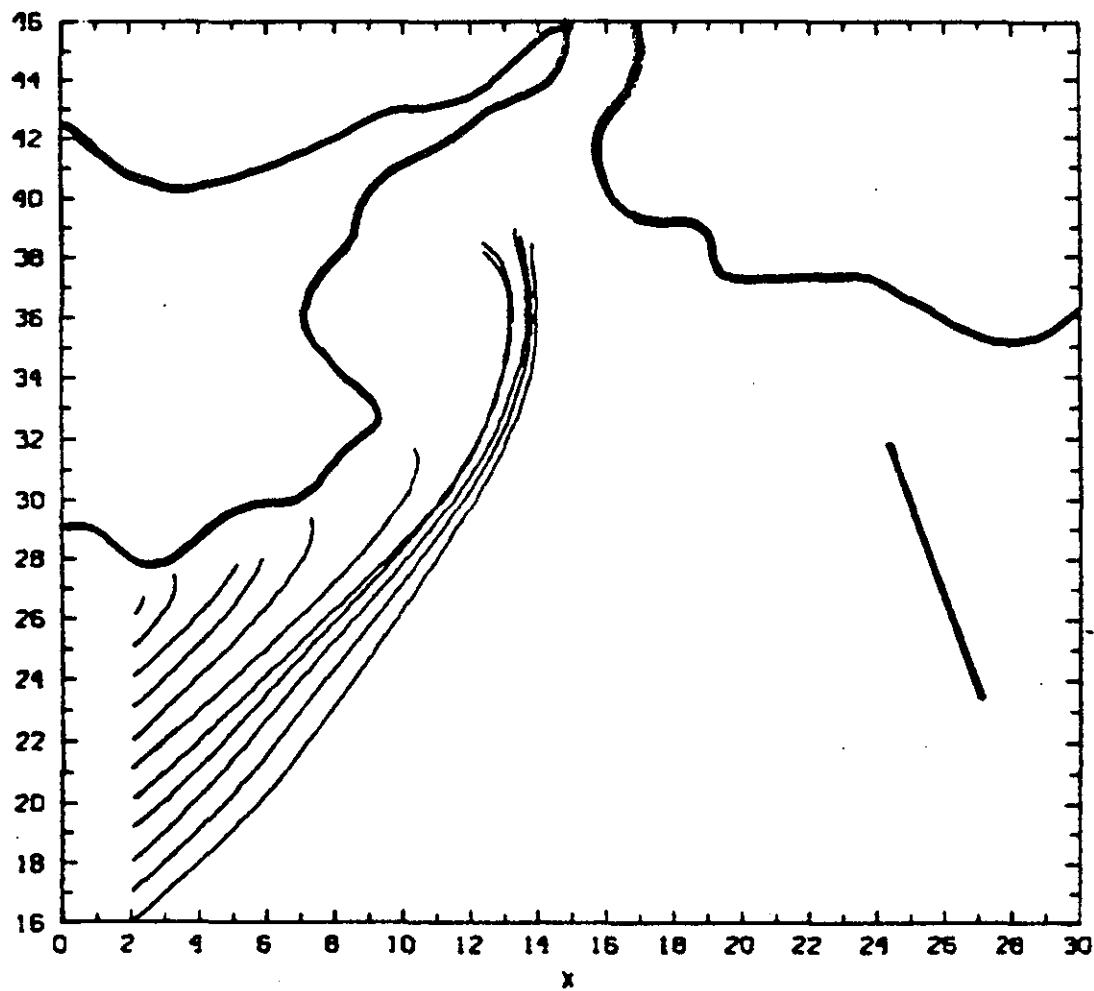
Figure 4-3 (b). Wave ray tracing: Waves from southwest.
Wave period 6 secs.
Mean low water + 0 feet.
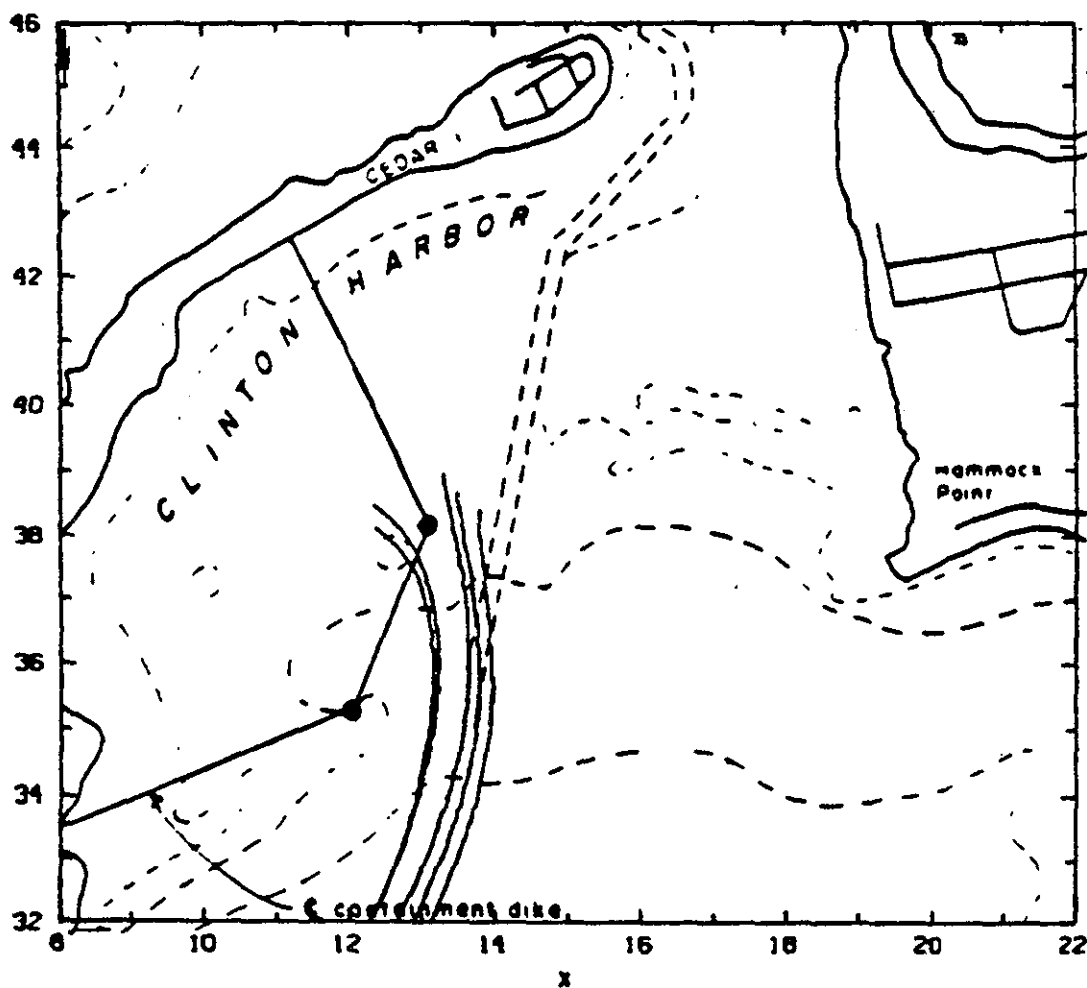
Figure 4-3 (c). Wave ray tracing: Waves from southwest.
Wave period 6 secs.
Mean low water + 0 feet.
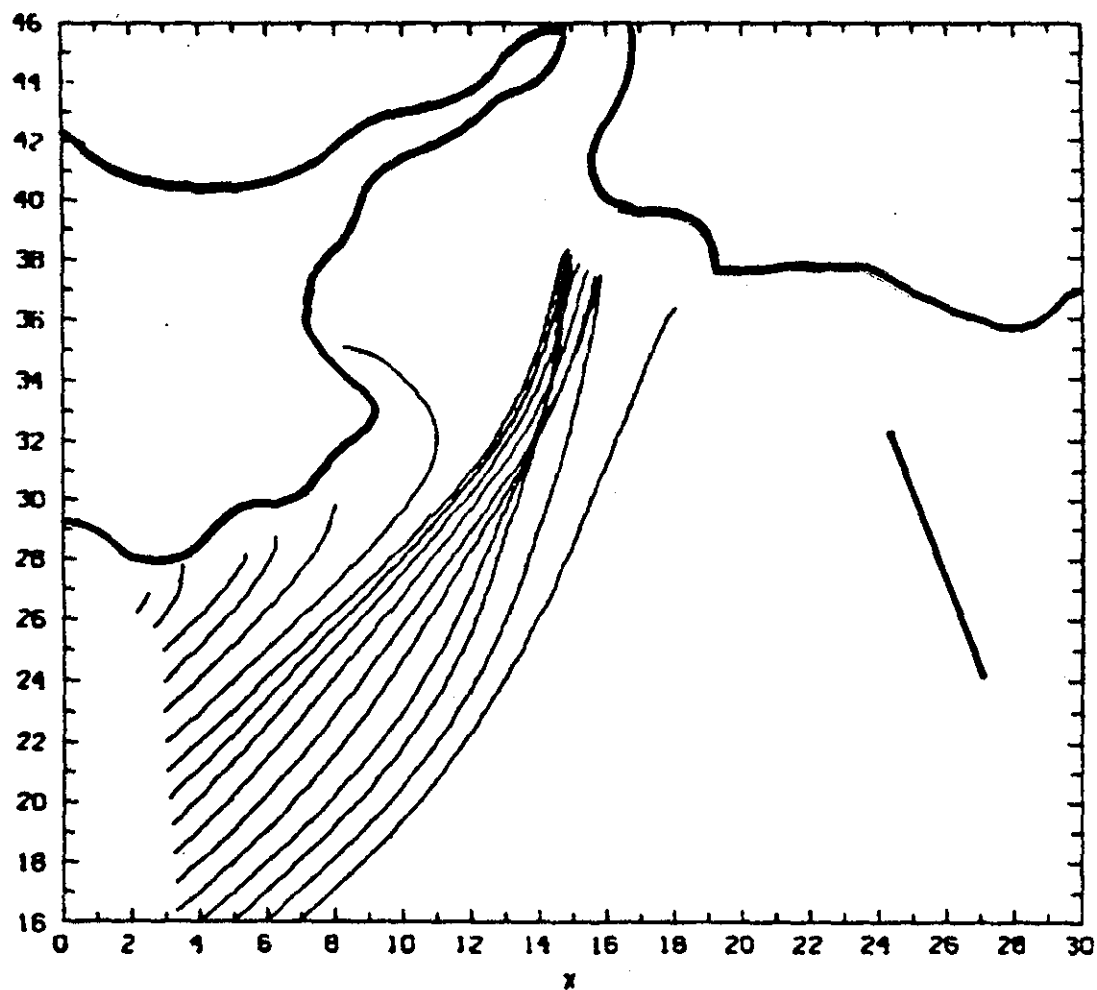
Figure 4-3 (d). Wave ray tracing: Waves from southwest.
Wave period 6 secs.
Mean low water + 3 feet.
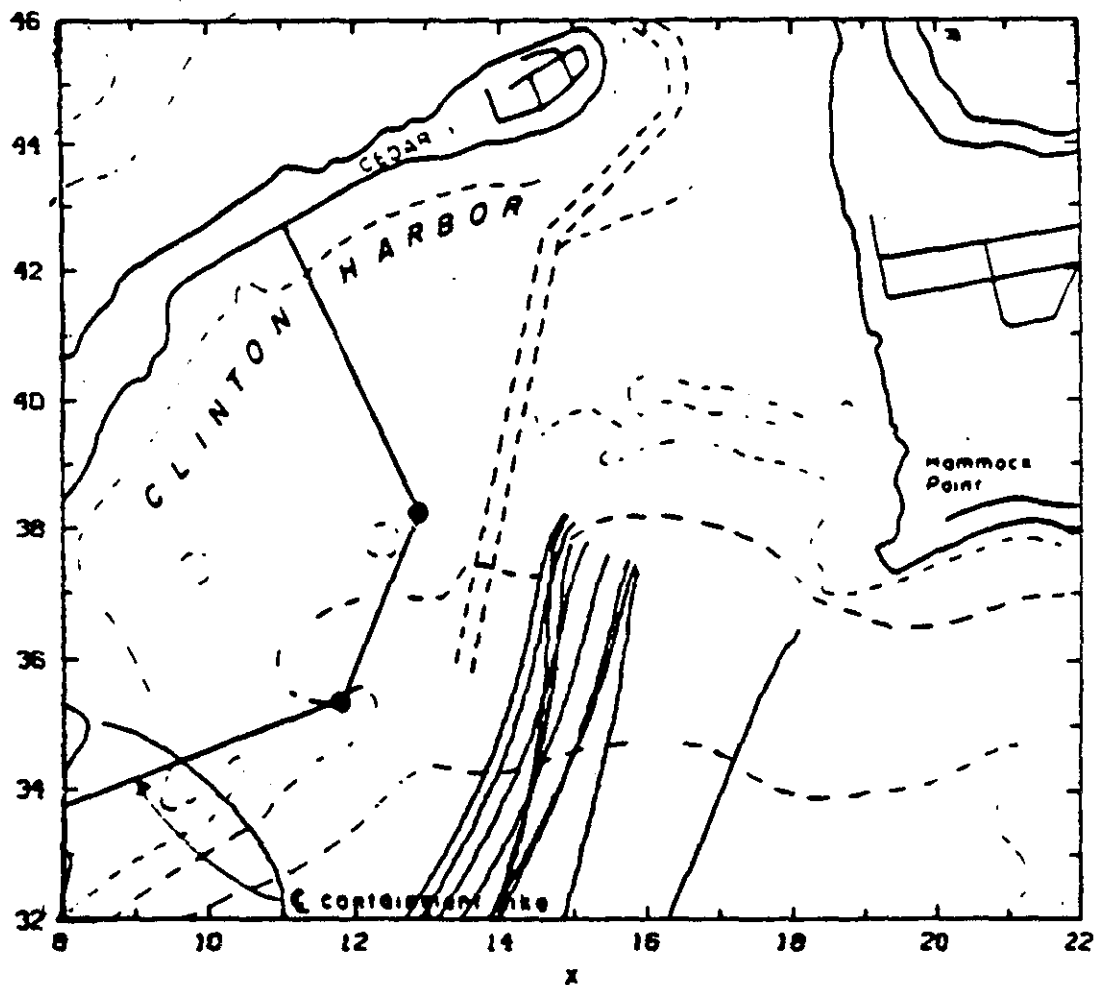
Figure 4-3 (e). Wave ray tracing: Waves from southwest.
Wave period 6 secs.
Mean low water + 3 feet.
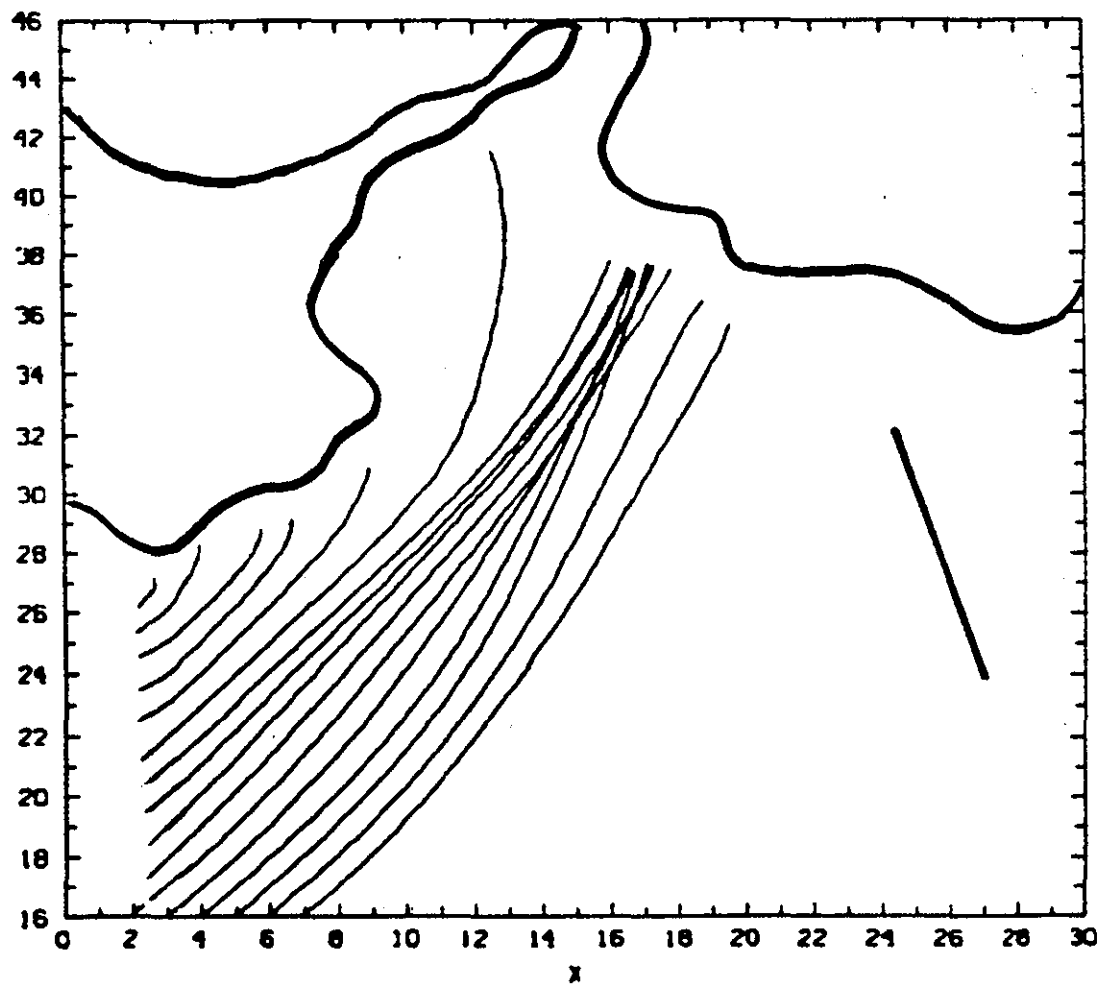
Figure 4-3 (f). Wave ray tracing: Waves from southwest.
Wave period 6 secs.
Mean low water + 8 feet.
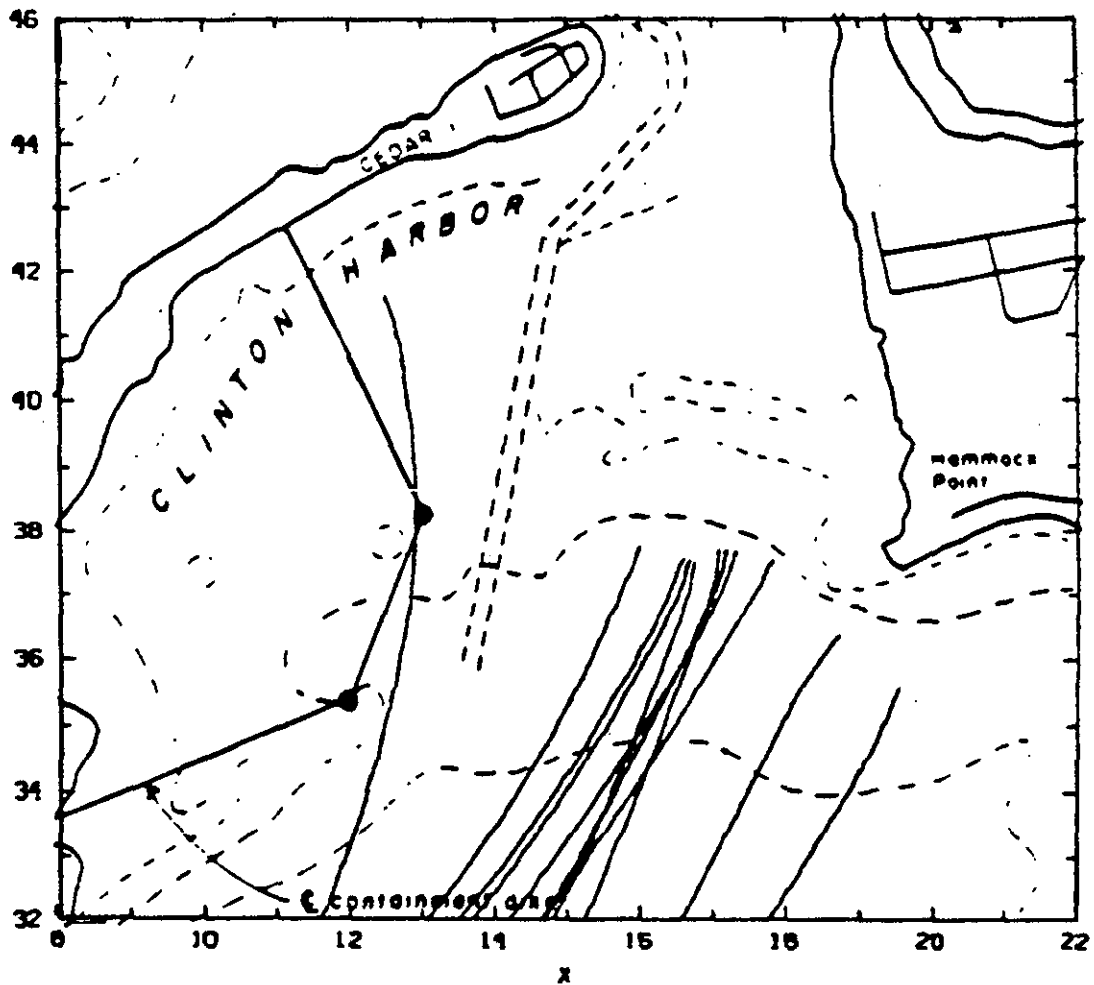
Figure 4-3 (g). Wave ray tracing: Waves from southwest.
Wave period 6 secs.
Mean low water + 8 feet.
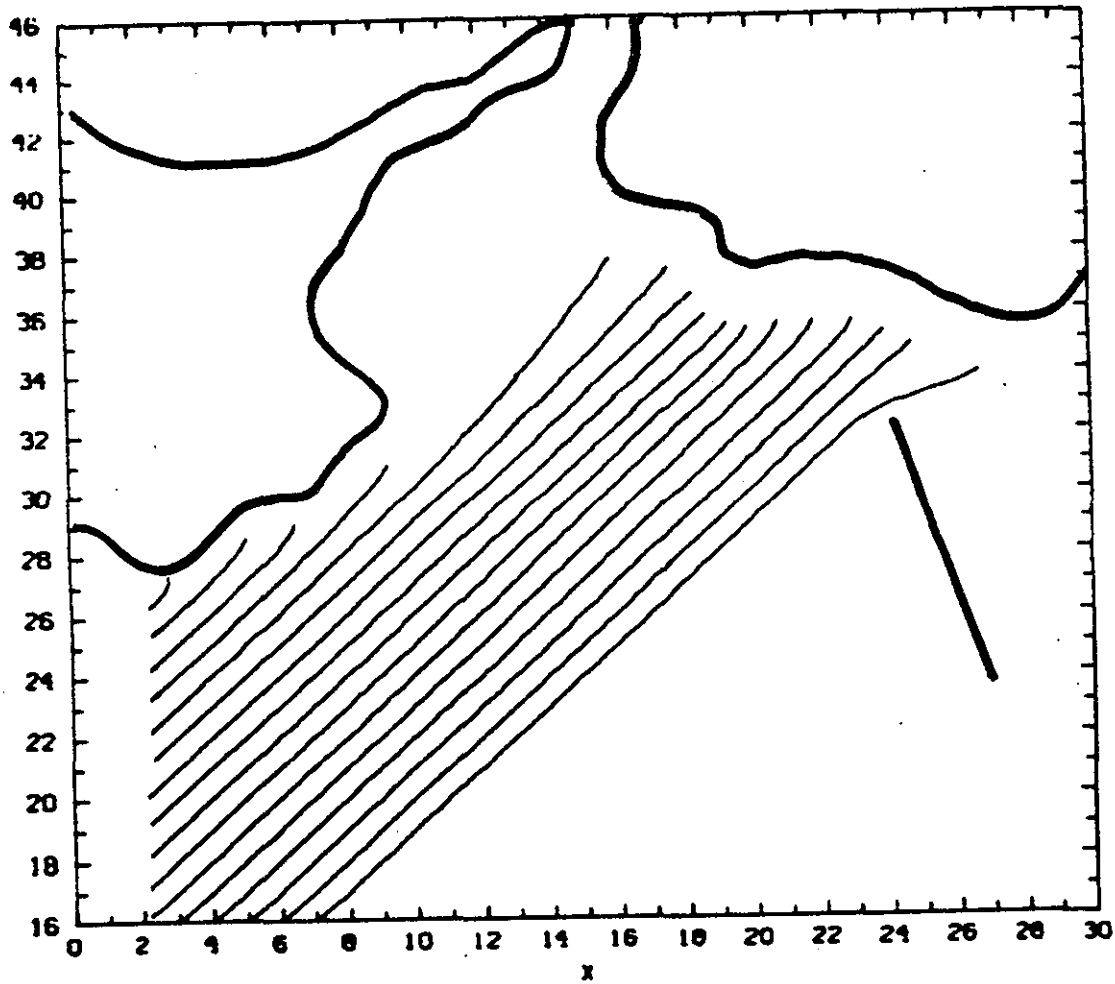
Figure 4-3 (h). Wave ray tracing: Waves from southwest.
Wave period 3 secs.
Mean low water + 8 feet.

Figure 4-3 (i). Wave ray tracing: Waves from southwest.
Wave period 3 secs.
Mean low water + 8 feet.

Figure 4-4 (a). Wave ray tracing: Waves from southeast.
Wave period 9 secs.
Mean low water + 8 feet.

Figure 4-4 (b). Wave ray tracing: Waves from southeast.
Wave period 6 secs.
Mean low water + 0 feet.

Figure 4-4 (c). Wave ray tracing: Waves from southeast.
Wave period 6 secs.
Mean low water + 3 feet.

Figure 4-4 (e). Wave ray tracing: Waves from southeast.
Wave period 3 secs.
Mean low water + 3 feet.

Figure 4-4 (g). Wave ray tracing: Waves from southeast.
Wave period 3 secs.
Mean low water + 8 feet.

Figure 4-4 (f). Wave ray tracing: Waves from southeast.
Wave period 3 secs.
Mean low water + 8 feet.
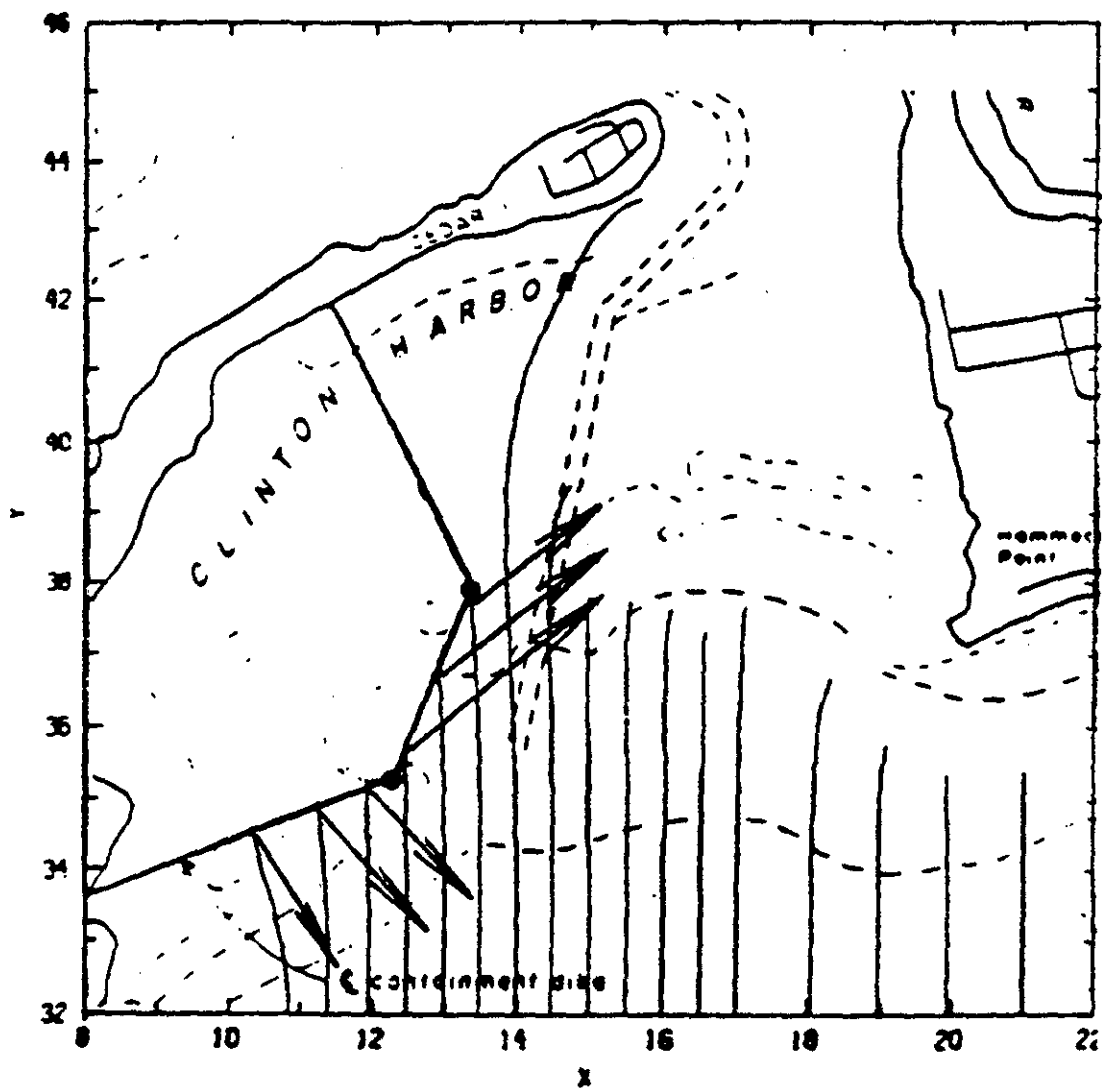
Figure 4-5. Potential reflection of southerly wave fronts off southeastern face of dike is toward northeast and into harbor.

4.5 Sediment Supply and Spit Stability

Placement of the proposed DMCF along the spit extending from Hammonasset Point to Cedar Island has the potential to: (1) interrupt the longshore drift of sediment along the spit; and (2) modify wave and tidal current energy affecting local transport of sediment. Interruption of longshore drift could result in erosion along the easternmost portions of the spit and increase its instability. Alternatively, reduction of incident wave energy due to DMCF sheltering could offset the reduction of longshore drift. The extent to which these potential impacts will be realized is difficult to quantitatively assess given the limited information available concerning the sources of sediment nourishing the spit and the associated preferred transport routes. However, a qualitative assessment is considered possible and is discussed below.

In total, longshore drift from outside the study area (Figure 1-1) is considered a minor source of sediment to the spit given the gradual long-term reduction in the volume of sediment supplied by the breakdown of Hammonasset Point and associated shoals and the continued stability of the spit. These characteristics favor the dominance of onshore-offshore transport of sediment and imply that the offshore area fronting the beach is the primary source of sediments maintaining the spit.

However, the consistent pattern of sediment accumulations along the western sides of the shore-perpendicular structures located on the south shore of Cedar Island are representative of a well-developed longshore drift system and could be taken as evidence of the significance of long-shore transport for maintenance of local beach stability. Any factor serving to

63

interrupt this drift has the potential to impact spit stability through a progressive retreat of the mean high water contour. This view cannot be simply discounted even though the volume of materials involved in this transport may be small in comparison to the volume moving onshore-offshore, and in fact may simply represent alongshore movement of materials first moved shoreward by the onshore-offshore system. In addition, the distributions of sediment associated with this transport appear to have contributed to measurable shoreline accretion, particularly near the eastern end of Cedar Island.

The proposed DMCF placement will initially serve to effectively block the longshore movement of sediment from Hammonasset Point to Cedar Island. In time, as sediment accumulation and transport along the toe of the structure proceeds, a new equilibrium will be achieved and some fraction of the pre-project transport will be re-established.

The DMCF will also tend to reduce onshore wave energy by limiting the advance of waves propagating from the south and southwest and thereby sheltering the spit from those components of the incident wave field. However, as indicated by the refraction plots, sheltering would not be complete as some portion of incident waves from the south would continue to reach the beachfront east of the dike. These energy conditions and the near-normal angle of incidence of the majority of waves along the eastern beach front favor continuing onshore-offshore transport and in combination with the abundant offshore sediment supply should be sufficient to maintain prevailing beach contours despite placement of the DMCF and possible interruption of the longshore sediment transport system.

In addition to direct and indirect impacts on the local sediment transport system, the DMCF also has the potential to affect spit stability through modifications of the spit's ability to respond to storm-related flooding and/or overwash. As discussed in Section 3.5, flooding and overwash have in the past resulted in rupturing of the spit and isolating Cedar Island from Hammonasset Point. These breachways have tended to form at a point approximately 3700 ft southwest of the spit tip (Figure 3-4). The DMCF will border this area and serve to reinforce the beachfront essentially precluding both storm flooding from the backshore and wave induced overwash from the offshore. Presence of the structure will tend to force future breaching to occur at points further east or alternatively would favor increased erosion rates along the distal end of the spit to provide the increase in channel capacity required to permit escape of inner Harbor flood waters. At present the washover area bordering the residential development on Cedar Island (Figure 3-4) suggests that breaching of this area would occur before the onset of significant erosion of the spit end. The potential for formation of this breach may be further increased due to focusing of wave energy induced by the close proximity of the northeastern segment of the dike.

The ultimate extent to which the DMCF will impact the Cedar Island spit through modification of breaching potential is dependent on a variety of factors including final composition of the dike face, future building plans on Cedar Island, and dredging plans for the Inner Harbor. The indeterminant nature of these factors effectively precludes simple quantification of impacts. Under such conditions it seems preferable to consider means to eliminate the cause of the potential impacts rather than continue

to analyze their probable extent. For the case of the DMCF, washover potential could be reduced significantly by mechanical placement of sand along the beachfront east of the dike and west of the Cedar Island residential area. Such placements would serve to increase dune elevation and favor growth of stabilizing dune grasses. The resultant increase in the strength and elevation of the dune line would limit foreshore or backshore attack or breaching to all but the most extreme storm conditions. Reduction of erosion potential along the eastern limit of the spit could be affected by incorporation of a flood drainage system within the DMCF. This system, operating only during extreme flood conditions, would provide an alternate drainage route for waters exiting from the inner Harbor. This would relieve the necessity for increases in channel capacity and thus the potential for increased erosion along the distal end of the spit. With these modifications in place, the proposed DMCF would have limited effect on breaching potential and through support of the storm drainage system could actually increase the stability of the Cedar Island spit.

4.6 DMCF and Clinton Harbor Sediment Transport

The sediment transport system active within Clinton Harbor represents the result of interactions between available sediment supply and local transport energy dominated by wind waves and tidal currents. Analyses conducted as part of this investigation indicate that the proposed DMCF will serve to modify each of these factors to some extent. Sediment supplies will be primarily affected through interruptions of the longshore drift system. Secondary impacts may be associated with materials supplied by the drainage waters from the DMCF; a difficult factor to quantify. The surface wind wave field will be modified due to reflections from

the face of the DMCF dike and will experience only minor variations due to wave refraction or diffraction. Tidal currents will be altered in both speed and direction due to the DMCF (Johnson,1982). Differences in the character of pre- and post-project sediment transport will represent integrated effect of each of these modifications.

Viewed as components of a system, the above range of impacts is expected to exert primary influence on the sediment transport field active in the vicinity of the southeastern segment of the dike. In this area wave reflections from the face of the dike favor propagation of wave energy to the north and east into the Harbor. Wave energy in combination with increased tidal velocities induced by DMCF placement (Johnson, 1982), serves to perturb the characteristic sediment-flow equilibrium prevailing within the Harbor and favor sediment displacement to the north-east during the flood tide and to south-east during the ebb. The magnitude and final direction of this transport will vary as a function of the intensity of wave-associated currents relative to those produced by the ambient tidal flows. Increasing wave- associated energy will result in transport with strong easterly components. Decreasing wave energy and the associated increase in the relative importance of the tidal stream favors progressive dominance of north-south transport. The horizontal spatial scale of this transport system will be limited by the shallow water depths prevailing within the Harbor and is expected to be characteristically less than 500 yds.

DMCF-induced wave reflection sediment transport favors material accumulations within the adjacent navigational channel (Figure 2-2). Although the effect of this transport will be offset

to some extent by the DMCF induced increases in channel tidal velocities, flow-sediment equilibrium considerations suggest that net deposition rates in the channel will increase if wave reflection is allowed to occur. The ultimate deposition rate will vary as a function of the selected channel controlling depth and the degree of wave reflection from the face of the dike. Maximizing the wave energy absorptive capacity of the dike face would minimize such deposition. Minimization of wave reflection in combination with DMCF-induced increases in north-south tidal velocities will contribute to the natural maintenance of the navigational channel.

In addition to DMCF impacts on sediment displacement near the southeastern face of the dike, the structure is also expected to modify transport near the intersection of the dike with the Cedar Island beach. In this area the configuration of the dike favors formation of a low velocity or "stagnation" zone leading to the preferential deposition of fine grained sediments. Formation of such a deposit, potentially accelerated by super-ambient concentrations of fine-grained sediments supplied by DMCF drainage and overflow, will modify the dike-beach intersection contours to a more curvilinear form and serve to redirect longshore tending currents. Such accretion will complement nourishment and drainage efforts discussed above and will increase spit stability.

At points remote from the structure DMCF placement will affect sediment transport primarily through modifications in the ambient tidal velocity field. Wave-related impacts will be primarily a near-field phenomena with the potential for distant impacts limited by shallow water depths within the Harbor. Analyses conducted as part of this investigation (Johnson, 1982)

68

indicate that DMCF placement will to some extent modify tidal velocities throughout the Harbor. The primary potential effects appear to be essentially confined to the navigational channel where post-project maximum velocities will be consistently higher than pre-project levels. As noted such increases are expected to contribute to channel maintenance provided wave reflection from the SE dike face can be minimized. At more distant locations the analyses indicate only slight increases in tidal velocity and suggest that large scale modifications in sediment transport associated with DMCF placement will be minimal.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Concerning the wave energy and sediment transport regime of Clinton Harbor the following conclusions are drawn from the analysis.

o The DMCF area is subject to relatively low wave energy exposure due to off-shore shoaling of the larger and higher energy deep water waves of periods 9 seconds and larger.

o The DMCF appears to be a zone of wave energy dissipation due to depth-induced refraction of waves onto the headlands of Hammonasset Point.

o The predominant direction of wave advance is from the south due to refraction-caused rotation of wave fronts propagating from the SW and SE directions.

o The primary mechanism supplying sediment to the Cedar Island beachfront is the onshore-offshore movement of sand induced by the near-normal angle of incidence of the residual wave fields along the beach front.

o The Cedar Island spit is subject to breakthrough during infrequent storm surge conditions as evidenced by historical coastal charts and photographs of the area.

Regarding possible impacts, placement of the proposed DMCF along the Cedar Island spit has the potential to: (1) interrupt the longshore drift of sediment along the the spit; and (2) modify wave and tidal current energy affecting local sediment transport. Analysis and investigation support the following conclusions:

o   The   proposed DMCF will exert primary   influence   through
structure-related   modifications of the incident wave field.
Possible impacts due to interruption of longshore   transport
will likely be offset by DMCF sheltering of the beach.

o   The   effect   of the DMCF on wave refraction   and/or   wave
diffraction characteristics appears minimal.

o   Wave   reflection effects off the SE facing   dike   section
will   potentially   influence maintenance of   the   navigation
channel due to generation of easterly energy components   and
resultant   sediment transport.   These impacts can be reduced
and   possibly   eliminated by designs favoring   maximum   wave
absorption along the SE face or realignment of the SE facing
dike segment .

o Sediment deposition is likely to occur in the vicinity   of
the   junction   of the eastern end of the DMCF dike with   the
Cedar Island spit.   This deposition will help stabilize   the
spit and protect it from breakthrough.   Mechanical placement
of   material   at the   currently evident overwash   zone   will
help ensure spit stabilization.

o   Avoidance of DMCF drainage outfalls on the easterly   dike
face   will   help   avoid possible   complications   with
maintenance   of the adjacent navigation channel.

o In areas remote from the DMCF dike,   placement will affect
sediment   transport   primarily through modifications of   the
tidal velocity field. With the exception of the navigational
channel (where DMCF related increases in maximum   velocities
should   assist in channel maintenance) these effects   appear
to be small.

5.2 Recommendations

(1) To avoid potential adverse sedimentation effects associated with reflected wave energy off the SE facing dike segment, consider one or more of the following design options:

o Reduce the slope of the dike to less than the presently proposed 21 degrees to essentially eliminate wave reflections; and/or,

o Apply wave absorbing materials, such as coarse-grained, large angular rip-rap, along the SE facing dike segment; and/or,

o Realign the dike to minimize the angle of incidence between the incoming wave field and the face of the dike. The wave refraction analyses provide data useful for this purpose.

(2) To avoid potential adverse effects associated with dredged material placement within the DMCF:

o Exercise care in the placement of the proposed drainage outfalls from the DMCF to avoid complications with channel maintenance. A westerly discharge point seems preferable.

(3) To avoid potential adverse effects associated with DMCF material placement on the stability of the Cedar Island spit:

o During DMCF construction, resand and stabilize the present washover area prevailing along the Cedar Island spit near the DMCF.

o Develop a storm drainage system within the DMCF sufficient to provide an alternate means of exit for waters trapped within the inner Harbor during extreme storm conditions.

Failure to provide an alternate exit for inner harbor storm waters could lead to excessive erosion at the eastern tip of the Cedar Island spit. Design of the DMCF storm water drainage features could be considered in association with interior drainage outfalls for effluent control during material placement.

(4) Initiate a regular profiling survey to monitor long term effects of the DMCF on adjacent depth contours and the profile of the adjoining beach.

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